TRANSACTIONS

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

VOLUME 34

THIRTY-FOURTH ANNUAL MEETING
NEW YORK, N. Y., JANUARY 23–26, 1928

SEMI-ANNUAL MEETING
WEST BADEN SPRINGS, IND., JUNE 26–29, 1928

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American Society of Heating and Ventilating Engineers

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1928

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1928

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TRANSACTIONS

of

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

No. 787

THE THIRTY-FOURTH ANNUAL MEETING, 1928

THE year 1927 produced a great deal of activity in engineering research in which the Society took a leading role in so far as it affected heating and ventilation and this fact was strongly emphasized at the 34th Annual Meeting held in New York, January 23–26, 1928. Every paper and report brought out the results of investigation in the laboratory or in the field and the evidence gathered indicated the need of more effective cooperation with allied organizations in research activities, an idea sponsored by the Society during the past year.

Seven sessions were held at this Annual Meeting and a registration of 497 members and guests was recorded.

The Report of the Tellers, given by Chairman J. A. Donnelly, indicated the election of the following:

President:	A. C. WILLARD
Vice-President:	THORNTON LEWIS
Second Vice-President:	L. A. HARDING
Treasurer:	W. E. GILLHAM
Members of the Council: (for 3 years)	H. H. ANGUS
	N. W. DOWNES
	ROSWELL FARNHAM
	F. B. ROWLEY
Members of Committee on Research: (for 3 years)	A. R. ACHESON
	D. S. BOYDEN
	R. V. FROST
	L. A. HARDING
	F. B. ROWLEY

The Committee on Increase of Membership reported the status of the Society membership as 1988 members on the roll.

The Report of the Council follows:

Report of Council

COMMENCING 1927, the members of the Council were elected in accordance with the terms of the Constitution providing that four men serve for three years, four men serve for two years and four men serve for one year, so that with the four elected officers and the last retiring past-president the Society is now governed by a group of seventeen men.

The new Council organized on January 28, 1927 in St. Louis, Mo., appointed its Executive, Finance, Membership and Publication Committees for the year.

The Bankers Trust Co. and the Bank of America were selected as depositories for Society funds and the Finance Committee was requested to prepare a budget.

A. V. Hutchinson was appointed Secretary and Manager of Publications for the year 1927 and W. H. Driscoll was selected as Chairman of a Survey Committee to consider matters relating to the Society's progress and welfare. Various invitations for Society Meetings were considered and White Sulphur Springs, W. Va. was chosen for the summer meeting 1927, and New York City was designated as the meeting place for 1928.

At the March meeting of the Council, the budget for 1927 was adopted and regulations governing the selection of the Nominating Committee were adopted. Walter Ford was appointed to solicit advertising for the Society's publications, and Perry West started his work as editor-in-chief of THE GUIDE.

The plan of permitting Chapters to offer a limited membership for the purpose of interesting men in Society activities was provided to cover the period until December 31, 1928. Several Chapters which have tried this plan have found it very effective and requested its continuation.

A booklet on members was prepared by a Society member, Esten Bolling, to assist the work of the increase of membership and this has been effective in getting a great many prospective members.

In accordance with the Constitution, the Council nominated five men as members of the Committee on Research 1928, and also during the year made a number of special appointments, among which were the following: E. S. Hallett, was designated to address the Superintendents Division of the National Education Association at Dallas, Texas; Messrs. Nusbaum and Lyle, appointed to serve as the Society's representatives on the Sectional Committee of the Refrigeration Safety Code Committee; R. P. Bolton and W. S. Timmis were appointed to serve on the Advisory Committee of the group working for the establishment of a museum of the peaceful arts; H. P. Gant, M. C. W. Tomlinson and A. V. Hutchinson were designated to draft regulations governing the preparation and presentation of meeting papers; Thomas Dugan was appointed to serve on the Committee revising the Standards for Pipe Threads; Thornton Lewis was appointed to investigate the possibility of having a heating and ventilating exposition; O. N. Walther representing the Society on the Garage Committee of the *National Fire Protection Association*.

West Baden Springs, West Baden, Ind. was selected as the summer meeting place for 1928, the dates to be June 26 to 29. The Council authorized the investment of additional Society funds in securities and these are referred to in the Report of the Finance Committee.

Consideration was given to a change in the size of Society publications but after a thorough investigation, it was thought best to standardize on the 6 x 9 size for all books or magazines issued by the Society.

At the request of Prof. E. O. Eastwood, activities were started on the Pacific coast for an active chapter to be known as the Pacific Northwest Chapter.

During the year, the Council accepted the resignations of 40 members and 133 were dropped for non-payment of dues.

Of the nine Council Meetings held during the year four were in New York and the remainder were held in Pittsburgh, White Sulphur Springs, West Baden, Philadelphia and St. Louis.

Respectfully Submitted.

F. PAUL ANDERSON, *Chairman.*

Report of the Finance Committee

President Anderson introduced Thornton Lewis, chairman of the Finance Committee who presented slides showing balance sheets for the Society's Research Funds, budget comparisons, and gave a statement of the important items which gave a complete statement of the excellent financial condition of the Society.

Report of Certified Public Accountant

January 12, 1928.

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS
29 WEST 39TH STREET
NEW YORK CITY

Gentlemen:

I have made an examination of the books of account and records of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York City, for the year ended December 31, 1927 and submit herewith the following exhibits, schedules and comments:

EXHIBIT

"A" BALANCE SHEET—DECEMBER 31, 1927
Schedule
No. 1—Marketable Securities

"B" STATEMENT OF INCOME AND EXPENSES OF THE SOCIETY—FOR THE YEAR ENDED DECEMBER 31, 1927
Schedule
No. 4—Salaries

"C" STATEMENT OF INCOME AND EXPENSES OF THE PUBLICATIONS—FOR THE YEAR ENDED DECEMBER 31, 1927
Schedule
No. 2—Cost of JOURNAL
No. 3—Cost of GUIDE
No. 4—Salaries

"D" COMPARISON OF BUDGET—SOCIETY ACTIVITIES

"E" COMPARISON OF BUDGET—PUBLICATIONS

CASH

The Cash on Deposit was verified by direct communication with the following depositories and reconcilement of the amounts reported to me with the balances shown on the books of the Society:

GENERAL FUND		
Bankers Trust Company	$8580.50	
Bank of America	2291.30	$10,871.80
RESEARCH FUND		
Bankers Trust Company		9,739.93
TOTAL CASH ON DEPOSIT		$20,611.73

STATEMENT OF SOCIETY'S FINANCES FOR YEAR 1927

BUDGET COMPARISON—SOCIETY ACTIVITIES

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

For the Year Ended December 31, 1927

	Actual 1927	Budget Provision	Increases° Decreases*
INCOME			
Dues—1927	$24,228.07	$25,000.00	$768.93*
Initiation Fees	2,465.15	3,200.00	734.85*
Sales of Emblems	122.50	200.00	77.50*
Interest Earned	1,347.54		1,347.54°
Profit from Sale of Securities	161.70		161.70°
TOTALS	$28,324.96	$28,400.00	$ 72.04*
EXPENSES			
Salary—Secretary	$2,500.00	$2,500.00	
Salary—Clerical	4,372.51	6,000.00	$1,627.49*
Rent—Room 602	1,000.00	1,000.00	
Professional Services	360.00	300.00	60.00°
Postage	1,153.94	1,500.00	346.06*
General Printing	853.52	1,250.00	396.48*
Yearbook	743.43	850.00	108.57*
Cost of Emblems	52.33	150.00	97.67*
Traveling—President	1,500.00	1,500.00A	
Traveling—Secretary	953.23	1,000.00	46.77*
Meetings	3,018.02	2,500.00	518.02°
APPORTIONABLE EXPENSES—60%			
Rent—Room 603	1,236.20	1,260.00	23.60*
Office Expense	1,180.76	1,300.00	119.24*
Office Supplies	364.07	600.00	235.93*
Allowance for Depreciation of Fixtures	243.37	300.00	56.63*
Exhibit—Power Show	83.65	150.00	66.35*
$2.00 per Member for Journal	3,908.00	3,800.00	108.00°
$1.00 per Member for Transactions	1,954.00	1,900.00	54.00°
	$25,477.03	$27,860.00	$2,382.97*
REALIZATION OF PRIOR YEAR'S DUES	$4,006.15	$6,520.66	$2,514.51*
SPECIAL APPROPRIATIONS			
Chapter Expense Allowance	$1,000.00	$1,000.00	
Boiler Code	628.62	628.62	
Code of Minimum Requirements	1,000.00	2,000.00	$1,000.00°
Publicity Expenses	618.39		618.39*
Rochester Committee Expenses	94.90		94.90*

NOTE "A." President's traveling allowance originally budgeted at $1,000.00 was increased to $1,500.00 at the November 7, 1927, Council Meeting.

Exhibit "D"

BUDGET COMPARISON—PUBLICATIONS

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

For the Year Ended December 31, 1927

	Actual 1926	Actual 1927	Budget Provision 1927	Increases° Decreases*
INCOME				
JOURNALS				
Advertising	$18,835.25	$20,190.28	$20,000.00	$190.28°
Sales of Journals	1,201.60	999.63	1,200.00	200.37*
$2.00 per Member from Annual Dues	3,928.00	3,908.00	3,800.00	108.00°
	23,964.85	25,097.91	25,000.00	97.91°
TRANSACTIONS				
$1.00 per Member from Annual Dues	1,964.00	1,954.00	1,900.00	54.00°
Sale of Transactions	1,148.90	672.50	1,200.00	527.50*
	3,112.90	2,626.50	3,100.00	473.50*
GUIDE				
Advertising	21,120.43	27,460.22	29,000.00	1,539.78*
Sale of Guides	3,891.30	3,997.49	4,500.00	502.51*
Sale of Reprints and Books	1,068.16	1,171.80	1,200.00	28.20*
	26,079.89	32,629.51	34,700.00	2,070.49*
	$53,157.64	$60,353.92	$62,800.00	$2,446.08*
COSTS AND EXPENSES				
COST OF PUBLICATIONS				
Journal	$11,891.06	$12,689.70	$12,500.00	$ 189.70°
Guide	14,385.18	14,643.99	16,500.00	1,856.01*
Transactions	2,989.48	2,442.03	2,500.00	57.97*
Reprints		796.55	1,200.00	403.45*
	29,265.72	30,572.27	32,700.00	2,127.73*
EXPENSES				
Salary—A. V. Hutchinson	2,508.36	2,500.00	2,500.00	
Salary—Clerical	5,057.00	3,511.00	5,000.00	1,489.00°
Professional Services	300.00	240.00	300.00	60.00°
Traveling—A. V. Hutchinson	1,029.57	749.91	500.00	249.91*
Postage	306.38	354.58	400.00	45.42°
APPORTIONABLE EXPENSES—40%				
Rent—Room 603	864.00	864.00	840.00	24.00°
Office Expense	534.01	726.93	800.00	73.07*
Office Supplies	427.70	243.15	400.00	156.85*
Allowance for Depreciation of Fixtures	146.65	162.25	200.00	37.75*
Salary—Perry West		3,000.00	3,000.00	
Salary—Solicitor		3,000.00	3,000.00	
Traveling—Solicitor		1,150.54	1,500.00	349.46*
	11,173.67	16,502.36	18,440.00	1,937.64*
TOTALS	$40,439.39	$47,074.63	$51,140.00	$4,065.37*

Exhibit "E"

MARKETABLE SECURITIES

The Securities kept with the Bankers Trust Company for safe-keeping were verified by direct communication. Market value of these securities exceeded the cost of acquisition by $40.58. Sales of Securities during the current year yielded a net profit thereon of $161.70 and Earned Interest amounting to $1130.02.

ACCOUNTS RECEIVABLE

Dues Receivable from Members were verified by trial balance and aging of the individual membership cards. The summary by years of the unpaid dues is shown below:

1927 Unpaid Dues	$ 9,398.37
1926 Unpaid Dues	3,062.26
1925 Unpaid Dues	245.00
1924 Unpaid Dues	50.00
TOTAL UNPAID DUES	12,755.63
LESS: Prepaid Dues	252.05
DUES RECEIVABLE	$12,503.58

After discussing the Dues Receivable with your Secretary, the Reserve reflected by the books of the Society for Dues doubtful of Collection was increased to $6500.00, which in my opinion provides against future contingencies. All other Accounts Receivable were determined and verified in the same manner as the Dues. A Reserve of $1000.00 to cover the probable loss in the realization of these accounts was also provided.

INVENTORIES

An Inventory of TRANSACTIONS taken as at December 31, 1927 may be summarized as follows:

Year	Volume	Quantity	Price	Amount
1921	27	220	1.00	$ 220.00
1922	28	168	1.18⅜	198.92
1923	29	138	1.97½	272.55
1924	30	267	1.38¼	369.13
1925	31	301	0.95⅛	336.11
1926	32	165	1.26⅝	209.22
			TOTAL	$1605.93

Consistently with prior practice, number 26 Transactions volumes for the year 1920 have been written off as inactive. A Reserve in the amount of $2500.00 has been estimated to cover the cost of production of volume No. 33 for the year 1927.

All other Inventories were determined either by actual count or computation.

DEFERRED CHARGES

An Analysis was made of the Expenditures for the purpose of allocating same to the proper years. Items such as Journal Wrappers and Drawings, Printing and Stationery, etc., applicable to 1928 operations have been included on the attached Balance Sheet as deferred charges to future operations.

ACCOUNTS PAYABLE

There remained unpaid as at the close of 1927 the sum of $1233.80 to Horn-Shafer Co. covering the cost of mailing the GUIDES which I have set up on the books as a current operation.

DUE RESEARCH LABORATORY

An amount equivalent to forty (40%) per cent of the dues charged to senior and associate members has been set aside for the Research Laboratory in accordance with Section 5, Article 3 of the By-Laws. The balance due the Research Laboratory as at December 31, 1927 for Dues was $4784.83. There is also due it the sum of $4022.55 for that portion of the GUIDE profit of the year 1927 which was computed as follows:

INCOME FROM GUIDE	$31,457.71	
COST OF GUIDE	21,794.53	
GROSS PROFIT		$9663.18
OVERHEAD EXPENSES		
Charged to GUIDE Calender Year 1926	$ 2,854.85	
LESS: One-half of reduction of 1927 expenses under 1926	909.92	1944.93
		7718.25
DEDUCT: Chapter Meeting Expenses		1000.00
DEDUCT: Bonus to Publication Management and Employees (58%)		2695.70
NET PROFIT FROM THE GUIDE FOR RESEARCH LABORATORY		$4022.55

ACCRUED ACCOUNTS

Bonus to the Management of Publications and Office Employees has been provided in accordance with resolutions passed by Council during the current year so as to reflect the additional compensation in the 1927 operations.

GENERAL FUND

An Analysis of the General Fund showing the changes that have occurred in this account during the year ended December 31, 1927 is subjoined.

GENERAL FUND—DECEMBER 31, 1926—PER FORMER REPORT		$31,683.53
ADD: Profit from Publications—Year ended December 31, 1927	$4608.99	
LESS: Loss for the above periods on Society Operations	493.98	4,115.01
GENERAL FUND—DECEMBER 31, 1927—PER BALANCE SHEET		$35,798.54

Respectfully submitted,

FRANK G. TUSA,
Certified Public Accountant.

Report of the Guide Publication Committee

YOUR Guide Publication Committee begs to report as follows:

THE GUIDE, 1928 appears in an entirely new "dress." It has enjoyed a very enthusiastic reception, which we trust will be as gratifying to you as to the Committee.

Many changes have been made in the data contained in this volume, which consists of 369 pages of technical information, 312 pages of catalog material and 56 pages in the membership section. The present volume contains about 100 pages more than the 1927 edition. About two-thirds of this increase is represented in the Technical Data Section and about one-third in the Catalog Data Section.

The organization of the work this year under a general Chairman and two Vice-Chairmen, acting as an executive Committee in close cooperation with the home office, with three Section Chairmen in charge of the heating, the ventilating and the catalog data sections respectively, has proven very effective.

The heating section was under W. H. Driscoll, the ventilating section under Samuel R. Lewis and the catalog data section under J. E. Bolling. These Chairmen selected their own active Committees and the results bear splendid testimony to their wise selections and to the invaluable services rendered by those selected.

These men with the assistance of a great many members of the Society produced the book as it has been delivered to you.

Special credit must be accorded the Society's Secretary and the home office staff working under his direction for keeping all of the Committees in active operation, handling all of the routine work, jealously guarding the high standards of the material used, securing the talent for special purposes, handling the physical production and so successfully holding and increasing the support of our advertisers.

Attention is also directed to the loyal support given by our Research Laboratory under its Chairman S. R. Lewis and Director F. C. Houghten, who furnished not only much research data but many of the computations needed for transforming this into GUIDE material.

Particular mention should be made of the important work done under the direction of Prof. A. C. Willard on the Heat Transmission data in Chapter I, and of the important work done on Pipe Sizes for Steam Heating Systems in Chapter III, which work resulted from the cooperative efforts of the Society's Technical Advisory Committee on Pipe Sizes under H. M. Hart, the Standardization Committee of the *Heating and Piping Contractors National Association* under R. S. Franklin and the Pipe Size Committee appointed by The Guide Publication Committee under C. V. Haynes.

Practically every Chapter in THE GUIDE was considerably revised and much new data were added both in the heating and in the ventilation sections. Further revisions are essential and it is hoped that much more progress will be made in 1928 than has been made during the past year.

As planned by the Council the work on the 1929 edition will be done under the direction of a technical director who will coordinate all data and present such data at a definite time for publication, thereby overcoming one of the difficulties experienced this year and making the date of publication earlier than was possible in the case of the 1928 book.

Statistics

The appended statistical report gives some interesting comparisons of the operations this year as contrasted with the previous year.

Income:	1927	1928
Advertising	$21,120.43	$27,460.22
Copy sales	3,891.30	3,997.49
	$25,011.73	$31,457.71
Expense:		
Printing	7,186.10	9,482.35
Sales promotion, booklets, etc.	1,832.70	2,505.77
Paper	1,783.40	1,763.71
Mailing	1,601.73	1,408.80
Engraving and art work, electros	324.50	645.70
Miscellaneous	62.87	189.19
Binding and mailing prior year's GUIDE		408.30
Special compensation	1,035.50	
Editorial		3,000.00
Solicitation		1,728.00
Traveling		662,71
	$13,826.80	$21,794.53

Distribution:

8300 Copies of THE GUIDE, 1928 were published of which 7000 were bound and the remainder are held in reserve. Distribution up to December 31, was as follows:

Members American Institute of Architects	2542	2615
Members A.S.H.&V.E.	1962	1954
Members Heating and Piping Contractors Natl. Association	700	682
Advertisers and their agents	240	260
Copies sold	800	600
	6244	6111
Size:		
Pages of advertising	284	312
Pages of text	304	368
	588	680
Copies Printed:		
Total copies printed	8025	8300
Total copies bound	7500	7000
Cost per copy	$1.79	$2,626
Income from Advertisement per copy	$2.73	$3,475

While a more advantageous printing contract was made, as is shown by our comparative detailed figures, the cost of composition increased materially because of the fact that so many changes were made from the former GUIDE. Changes in binding and a greater number of books also made an increase in cost. You will note that a charge for binding and mailing last year's GUIDE is also included. The corrections and changes were materially higher, particularly because of the work that had to be done on the Pipe Size Section which included a great deal of resetting. If this can be avoided profits in the future will be better. Even though 100 additional pages were added the cost for printing would have been very close to that of last year except for the large number of changes and corrections that were found to be necessary and the overtime that had to be paid for in producing the book.

Because of the fact that additional expense was incurred for editorial work and the addition of salary and expense for an advertising solicitor it can be seen that the actual production cost of THE GUIDE this year as compared with last is very close. However, because of the additional income resulting from the intensive promotion and solicitation campaign the income was increased to such an extent that the gross profit of THE GUIDE was only slightly under the amount obtained in 1927.

Briefly the cost per copy increased eighty-four (.84) cents while the income per copy increased seventy-five (.75) cents. The gross profit was approximately ten thousand ($10,000.00) dollars as against eleven thousand ($11,000.00) dollars last year.

It is expected, however, that results in this year's work will bring greater dividends for the next edition and that a substantial increase in profit will be shown for the coming year.

Recommendations

With the feeling that it will be your desire to make use of past experiences, the Committee has the following recommendations to suggest:

1. That the fundamental principles upon which THE GUIDE was founded and which have been so largely responsible for what ever measure of success it may have attained, *i. e.*, that the text section contain all of the latest and best data on Heating and Ventilating in readily usable form, entirely free from bias or propaganda and that the Catalog Section contain useful technical cuts, explanations and data, free from unnecessary selling talk or odious comparisons, be adhered to as strictly in the future as in the past. We simply wish to set this up once more as the bed rock upon which this undertaking rests.

2. However good the reaction to the present edition may be we must advise you that there is much room for enlargement, corrections and refinements. The following are a few specific items and others will be added as occasion requires.

(*a*) The Society's Standards and Codes should be added at least by title with brief synopses and references as to where complete data can be found.
(*b*) The Heating by radiation section should include data on different kinds of radiators. This requires more research work by our Laboratory.
(*c*) Steam heating return pipe sizes should be studied and revised. This requires more research work by our Laboratory or from other sources.
(*d*) The section on hot water heating and piping system should be made more practical.
(*e*) The section on steam and hot water boilers should be enlarged.
(*f*) The unit heating and air conditioning section needs enlargement.
(*g*) Ventilation standards need simplifying and modernizing. Data on summer time requirements should be added. This requires more research by our Laboratory.
(*h*) A chapter should be added on kitchen, laundry and hospital equipment and piping systems for same.
(*i*) A chapter should be added on Central Heating.
(*j*) A chapter should be added on heat transmission data and piping systems for water heaters, oil heaters, etc.
(*k*) A chapter should be added on pipe and fittings.
(*l*) Data should be added on the selection of fans for ventilation, drying, exhaust systems, collecting systems, mechanical draft, etc.
(*m*) Data should be added on fan furnace warm air heating.

3. It is the opinion of your Committee that the foundation which has been so well laid and builded upon by many of the same authors from year to year is now well established so that the present requirements are more along the lines of such enlargements and additions as would best come from the editing and compiling of the experi-

ences and data from a greater number and variety of our members and others engaged in the field.

It is our recommendation, therefore, that the active Committee for the compilation of the 1929 edition be selected largely from among those who have not as yet been given an opportunity to give of their experience and data and that a Consulting Committee or Board be organized, composed largely of those who have served in the past, and perhaps some of the leading captains of our industries, for viseing and checking the work of this Active Committee.

It is also recommended that the work be divided into smaller units so that no one member of the Active Committee will have more work than he can rightly cover. Also that the geographical and chapter distribution of the Committee members be made as uniform as possible, consistent with the available talent, so as to cover the variations of data and practices throughout the country and among the various chapters.

This we feel will work out to a better advantage this year, especially since more time will be available for editing and coordinating this data.

It is recommended that the idea of a small executive committee for cooperation with the home office organization be retained, and that the Chairman of the Research Laboratory be included as a member of this Committee. Also that the idea of sectional Chairmen be retained.

4. It is recommended that close attention be given to the coordination of the work of the various Committees of our Society and of the Committees and organizations of Allied bodies with the work of THE GUIDE.

In the present edition we were fortunate in cooperating for the first time with the *Heating and Piping Contractors' National Association* on Steam Heating Pipe Sizes and with the *Industrial Unit Heater Association* on Heating with Air, but this kind of cooperation should be extended to such organizations as: The Boiler and Radiator Manufacturers, the Fan Manufacturers, the Unit Heater Manufacturers Association, the Insulation Manufacturers, the Weatherstrip Manufacturers, the Heating Systems Manufacturers, the Hot Water Heating System Manufacturers, the Laundry, Kitchen and Hospital Equipment Manufacturers, Pump Manufacturers, the Warm Air Furnace Manufacturers, the *American Gas Association*, the Pipe Manufacturers, the U. S. Bureau of Standards, the National Trade Extension Bureau, the American Engineering Standards Committee, the U. S. Commission for the Prevention of Waste and the New York State Commission on Ventilation.

5. That an intensive drive be made to get all of the manufacturers to include sufficient data to eliminate the necessity of a user of THE GUIDE wasting time and patience over a lot of heterogeneous pamphlets and catalogs and so as to make THE GUIDE so complete as a catalog reference for architects, engineers and contractors that it will be unnecessary for them to bother with a general catalog file except for comparatively few of the isolated details of the products to be included in the design and specifications of heating and ventilating equipment.

6. That a cooperative movement be undertaken to have the manufacturers in this field standardize on the page size used in THE GUIDE for their catalogs so as to make this material interchangeable for use in both and so as to have as much catalog data as possible issued in the same size pamphlets for more ease and convenience in filing and handling.

Respectfully Submitted,

PERRY WEST, *Chairman*
W. H. CARRIER, *Vice Chairman*
C. V. HAYNES, *Vice-Chairman*
W. H. DRISCOLL, *Chairman*, Heating Section
S. R. LEWIS, *Chairman*, Ventilation Section
J. E. BOLLING, *Chairman*, Catalog Data Section

Report of Publication Committee

The Publication Committee has presented to the Society this year 12 issues of THE JOURNAL, THE TRANSACTIONS, 1926 and has cooperated with the Guide Publication Committee in the production of THE GUIDE, 1928.

For THE JOURNAL a great many manuscripts have been reviewed and it has been found that there is a great necessity for definite regulations regarding the preparation of paper for presentation to the members of the Society. It has been necessary to have many meeting papers rewritten and it is hoped that the definite regulations being prepared by a Special Committee will make this unnecessary in the future.

There is a noticeable tendency, however, on the part of many authors to inject propaganda of a commercial nature or favorable to a specific product into the papers that are offered for publication which is unfortunate for it is our aim to maintain a high grade of excellence for Society presentations. These points are merely brought out for the information of future publication committee members so that they may see clearly some of the problems that may confront them when they serve in this particular branch of the work.

Much excellent information has come through the Research Laboratory and already the cooperative research arrangements with Universities is bearing fruit in the form of good papers. The policy of the Committee this year has been to present results of study and a wide variety of subjects and divide the presentations equally on subjects that are of interest to heating and ventilating engineers.

It is gratifying to know that the financial showing of the Publication Department is very satisfactory and a few comparisons may be of interest.

	1927	1926
Number of issues—12		
Number of copies	31825	31700
Cost per copy	34c	37c
Income from Advertising per copy	64½c	62c
Editorial Section	762	940
Advertising Section	596	550

Total income from THE JOURNAL amounts to $25,097.91, and the cost of printing is $12,689.70.

THE TRANSACTIONS, Vol. No. 32 for 1926 was issued during the year and was distributed to the membership. The income from TRANSACTIONS was $2626.50 and the cost was $2442.03.

THE GUIDE, 1928, has already been distributed to 6111 people up to December 31 and 8300 copies were printed. A demand for this volume is exceedingly active and it may be necessary to make reprints in excess of the original number printed.

THE GUIDE

	1928	1926–27
Books printed	8300	8035
Pages	749	644
Cost per copy	$2.62	$1.79
Income—Advertising	3.47	2.73

Considering the total business done by the publications during 1927 the income from all sources amounted to $60,353.92. The publication and administrative expense amounted to $47,074.63.

The net profit reported by the accountant amounted to $8631.54 which is about $1500 greater than for the previous year.

Respectfully submitted,

F. B. ROWLEY, *Chairman.*

Report of the Committee to Cooperate with the Rochester Board of Education on School Ventilation Tests

NO PROGRESS has been made on the arrangements for these tests since last March, almost a year ago, but this Committee has very carefully refrained from making a final report, or any statement, for fear that such might interfere with the success of the undertaking.

It would seem, however, that the time has now arrived to present some of the pertinent facts, so as to clarify the atmosphere, which may have become considerably befogged by the various statements which have been given out from other sources from time to time, and so as to review these facts while they are fresh enough in our minds to be of some benefit towards the better guidance of such undertakings in the future.

It is our opinion in this connection, that if all of the principal facts leading up to and associated with this undertaking are studied by those who are interested in having the real truth about schoolhouse ventilation established, a great deal of good will be derived from this attempt of the Rochester Committee to solve this very important problem.

We shall only attempt in this report, therefore, to summarize the causes and effects which have led to the present status of this undertaking and to endeavor to point out how some of the resulting difficulties may be avoided in the future.

The idea of these tests was inaugurated under the auspices of the Tuberculosis and Health Association of Rochester and Monroe County, Rochester, N. Y., through their Indoor Fresh Air Committee.

The original purpose of this Association and its Committees was to have the Board of Education inaugurate open window ventilation so as to prove that this form of ventilation, as outlined by the report of the New York State Commission on Ventilation, was the proper one for schoolhouse use.

Early in their activities they were confronted with questions from various citizens of Rochester as to this being the wisest course to pursue and were finally persuaded to try out other systems of ventilation and to enlist the cooperation of a Citizens Committee, a Committee of the local physicians and health officials, a Committee from the *American Public Health Association* and this Committee from the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

Dr. George T. Palmer who was connected with the New York State Ventilation Commission and who has since specialized on school ventilation studies was employed to consult upon and supervise the making of these tests. He has remained on the job throughout the endeavors to get these tests started.

After many meetings and conferences it was finally decided that tests extending over a period of at least two years should be conducted on one school with window or uncontrolled ventilation and on another school with mechanical or controlled ventilation for the purpose of deciding which of these two kinds of ventilation is better for the health and comfort of school children.

Recommendations were received and approved from our Committee and from the *American Public Health Association's* Committee for the physical modifications in the two schools to be tested.

The primary and ultimate object sought, as a result of these tests, *i. e.*, to further the determination of the kind of schoolhouse ventilation which is most conducive to the health and comfort of school children, was agreed to by all parties concerned.

All parties concerned except the Department of the Board of Education in charge of buildings, certain members of the Citizens Committee and our Committee apparently held to the idea that the records of sickness and absence due to respiratory diseases of the pupils should be the sole basis for the interpretation of the results, while these other parties concerned believe that the health and comfort of the pupils as affected by the quality of the ventilation should be the basis.

Those who favored the sickness and absence record basis were in favor of proceeding without any definite basis for interpretation, but all such arrangements finally came to a halt due to the fact that the Board of Education refused absolutely to spend any money on these tests unless a definite basis for the interpretation of the results was set up and agreed to by all parties concerned before the physical work was started.

Eventually all arrangements were made and a complete set up for the tests agreed to, with the exception of some of the minor items of the relative weights of some of the factors to be used in the method of interpreting the results.

We understood that this plan was to have been submitted to the Board of Educa-

tion and to have been proceeded with after satisfactory adjustment of the slight differences then existing, but for some reason this was never put into effect.

Later, it was proposed to set up two standards of interpretation, one based on the records of illness and absence due to respiratory diseases and the other based on the physical quality of the indoor atmosphere as compared with a modification of our Laboratory standards for ventilation perfection, without any definite relationship between the two, so far as the final interpretation of the results was concerned.

We advised against this dual basis but were willing to consider it provided the proper methods were set up for both the physiological and the physical data observations.

This plan was finally rejected by the Board of Education for the reason that the modified standards as agreed to by us for the evaluation of the physical quality of the ventilation would not be agreed to by some of the other parties concerned, who insisted upon not only setting up the standards for the physiological determinations but also for the physical determinations, and the Board was unwilling to proceed without better agreement between all parties concerned.

Failing in all of this, we suggested to those in charge that the Board of Education be given all of the data and suggestions from the various sources, with the recommendation that the Board then set up its own rules for the tests and their interpretations and submit these to the various Committees concerned, stating that we would work under any kind of a plan that seemed to promise any reasonable surety of success. This proposal was never put into effect.

Finally the committee in charge proposed to the Board that the tests proceed with a very broad and flexible scheme of evaluating the physical conditions of the ventilation with wide variations in temperature, humidity, air motion, CO_2, dust, odors and bacteria, without penalization and with no scale for penalization above or below the regions of no penalization for these factors. This was too indefinite and was tabled by the Board of Education.

In addition to the above, the spirit of competition persisted, and gave evidence of continuing in such manner as to cloud the real issue—*the truth*.

There were so many participating committees that the responsibility was divided and it was impossible to settle on a coherent program. The buildings available were so old that to equip them with adequate apparatus involved excessive investment.

Our Committee has signified its willingness to cooperate with the Rochester Board of Education whenever conditions change to the extent of eliminating these objections, which have so far, despite our faithful efforts, proved insurmountable.

This is where the undertaking stood a year ago and is where it stands today. In our opinion the entire project is dead with little hope of resuscitation in sight, but for the better guidance of similar undertakings in the future, we would suggest the following:

1. All tests should be conducted under the direct auspices of the Board of Education of the City of Rochester, with whatever technical advice required reporting direct to it instead of through a loose complication of Committees who may or may not be predisposed towards some particular system.

2. All scientific data in existence should be reorganized and utilized from the start and such phases as are of a research nature should be as determined in Laboratories and the undertaking be confined to such field test data as cannot be better gotten from the Laboratory.

3. The undertaking should be gone about scientifically, quietly and systematically with all ideas of publicity and sensationalism eliminated.

4. The highest authorities on medical and health matters should be called upon to establish standards for the physiological reactions and the highest authorities on ventilation and air conditioning should be called upon to establish the physical standards of ventilation.

5. The tests should be conducted in new school buildings with the most approved and comparable equipment and in comparable localities as to surroundings, class, age and stock of pupils.

6. Complete records should be taken on the health and comfort of the pupils, the physical properties of the indoor and outdoor atmospheric conditions and on the economy and ease of operation.

7. A definite basis of interpretation should be established before the tests are started.

We beg to report with this the conclusion of our labors and respectfully ask to be discharged.

Respectfully submitted,

A.S.H.&V.E. COMMITTEE TO COOPERATE WITH THE ROCHESTER BOARD OF EDUCATION ON SCHOOL VENTILATION TESTS.

PERRY WEST, *Chairman*
WILLIS H. CARRIER, *Vice-Chairman*
A. R. ACHESON — ALFRED KELLOGG
DR. E. V. HILL — SAMUEL R. LEWIS
JOHN HOWATT — C. L. RILEY

Report of Committee on Research

By SAMUEL R. LEWIS, *Chairman*

THE carrying on of the Chairmanship of the Committee on Research during 1927 has been a wonderful pleasure. It has given me contact with the most interesting work in the world, conducted by the most interesting men in the world.

There have been no dissentions in the administration, probably because the Committee on Research has given me my own way; always, however, furnishing friendly advice and the most perfect cooperation.

This committee of fifteen men merits the study and observance of A.S.H.&V.E. members.

This committee has in charge the most vitally potent service that any organization can give the public. Its work does affect public health and comfort most profoundly, interlocking intimately with that of all public health functions. Its work also, in the light of more efficient use of materials, affects vitally the public pocket.

No small part of the glamour which surrounds the doing unselfishly of a public service is the bearing that the work of the Committee on Research holds toward little children in their schools, as to their comfort and health.

Another angle, more psychological, is the contacts now established by the committee with the cream of the next generation through cooperative research in the universities.

Let us get behind us the ever-present but not necessarily irritating question of finances. The present administration inherited a fund of $10,000.00 which was held as an emergency, drawing interest at savings bank rates.

We have maintained this fund.

We have collected from the Society, as our share in the dues of the members, the sum of $14,794.66.

The foregoing is that collected to December 1, with an estimate of December collections. There is perhaps the sum of $2500.00 yet to come from delayed dues.

We received in 1927 $4401.60 from THE GUIDE, and $14,198.63 from friends.

We expended $3000.00 for cooperative research with universities, $6361.88 for equipment, supplies, traveling, etc., and $26,074.15 for salaries.

Total income was $33,395.89.

Total outgo was $35,436.03.

There was an apparent deficit of about $2000.00, but this is only apparent, since delayed collections will cover it. We will doubtless have opportunities to make additional cooperative research agreements in 1928. We will need to collect more money from our friends in 1928 than we have collected in 1927.

There is no reason to apprehend any very great change for the next year. It may be that some of the work under way at Pittsburgh can be completed, or that its further study can be carried on to better advantage at some of the several research laboratories with which we are now developing cooperation. A dollar often will go further and do more public service when invested in this way than when invested in research at Pittsburgh.

The Research Endowment Fund has been established, founded by the Illinois Chapter. Several of the other chapters have promised to join in the foundation. Any surplus of income over disbursement can now be added to the Endowment Fund. This fund is to be administered by certain officers of the Society, in ways which are considered safe, but which will have the same flexible sort of government as has characterized the Laboratory from its inception. We wish to encourage the habit, now that this fund is in being, of our members to add to their life insurance a modicum for the Research Endowment Fund, to put something for it into their wills, and for corporations to put some of their stocks in its name, so that as business may prosper due to Research activities, the Laboratory may share in the reward.

The use of our Research facilities by associations of interested manufacturers, inaugurated at the winter meeting of January, 1927, at St. Louis, is being developed. We have completed and reported on window leakage in the Southwestern Bell Telephone Building in St. Louis for a group of weather strip and metal window manufacturers.

We are at work at Madison, on extensive research on infiltration of air through walls for the *National Association of Common Brick Manufacturers*. There are several other similar services being developed, and a great deal of correspondence and investigation has been done along these lines. It is by no means improbable that we shall eventually earn enough money in this way to carry the Laboratory.

THE GUIDE has been given some $800 of Research Laboratory money and service in developing the pipe size tables, beside the considerable time given by the staff to revising the heating and the ventilation sections, all without direct compensation.

In this connection it would appear highly desirable that the engineering data section of THE GUIDE should emanate from the Laboratory, perhaps eventually blending THE GUIDE Publication Committee into the Committee on Research.

The Director of the Laboratory and the Chairman of the Committee on Research

have devoted some time and a little traveling expense to coordinating research, to the extent of having visited several Universities, advising them in the kind of research work they shall plan to undertake, and assisting in the design of the equipment.

Likewise, some time has been given to cooperation with the Cleveland Board of Education in work similar to that which failed at Rochester but which has every indication of succeeding at Cleveland.

All of the laboratories at which cooperative research is being carried on have been visited by the administration, and the work is being safeguarded in every possible way.

Many of the chapters have been visited, to tell them of the work going on in Research.

Committee on Infiltration

A. C. WILLARD, *Chairman*

FOR several years the Research Laboratory of the Society has had under way an investigation of the infiltration of air into buildings. This work really began with the studies by F. C. Houghten and C. C. Schrader of the infiltration of air around window sash and frames with both plain and weatherstripped sash. At the same time a few tests were also made of the infiltration of air through a 13-in. brick wall plastered on the inside, and a surprisingly high leakage value per sq. ft. of wall area was reported. These early reports appeared in the JOURNAL of the Society in February and June of 1924, and in January of 1925.

With the organization of the Technical Advisory Committee on Infiltration, it was believed desirable further to investigate the wall leakage factor which had been obtained in the earlier tests, and a series of brick walls, plain, plastered and painted, have been tested at the Pittsburgh Laboratory. The later results indicate that the original leakage factors were too large, and that, in general, a well-plastered wall has a very small leakage factor which may be still further reduced by painting.

In addition, to the brick walls which have been tested, plastered frame walls with wood siding and stucco and hollow tile walls, both with and without plaster, have been under investigation. Results of these tests at the Pittsburgh Laboratory will be reported upon in detail by Director F. C. Houghten, and will finally be published in the JOURNAL of the Society.

Last April an agreement was entered into between the Society and the Steam and Gas Engineering Department of the University of Wisconsin, providing for cooperative research to determine the air infiltration into buildings through walls and around window sash and frames. The agreement provides for an expenditure per year of $1000.00 by the Society and an equal amount by the University. The agreement is for one year with the understanding that it will be continued if the results of the first year's work proves mutually agreeable.

On account of certain restrictions relating to the University's research funds, it was decided to use the Society's money to cover the expense of building steel frames to support the walls, to purchase the material for building the walls, and to prepare the walls for testing. It was understood that the University's share was to be used to pay the salary of a research fellow to be appointed for the purpose for the school year of 1927–28, or to pay the part-time salary of an instructor who should devote not less than half time to this research project.

FIG. 1. AIR PLANE VIEW OF PART OF THE CAMPUS, UNIVERSITY OF WISCONSIN. LAKE MENDOTA IS AT THE RIGHT

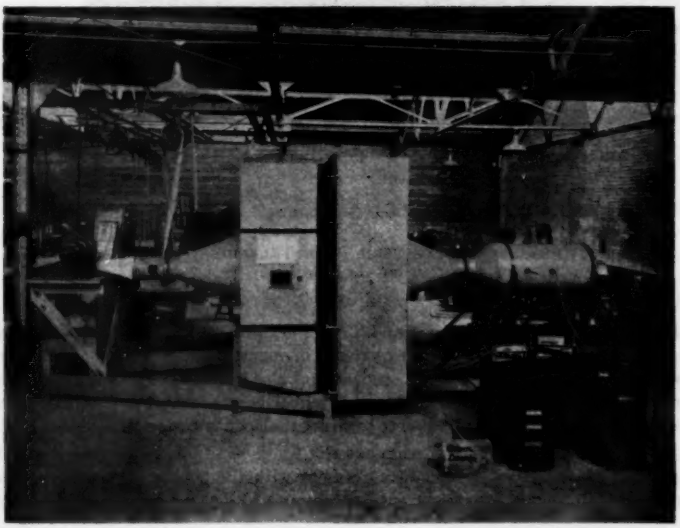

FIG. 2. AIR LEAKAGE RESEARCH EQUIPMENT, UNIVERSITY OF WISCONSIN

The agreement was entered into so late in the school year that very little was accomplished before college closed in June. However, considerable correspondence was carried on and some meetings were held to determine the number and the nature of the walls to be tested. Arrangements were made with the University Board of Regents to appoint W. M. Richtmann, instructor in steam and gas engineering, to devote half time

FIG. 3. SOUTHWESTERN BELL TELEPHONE BUILDING, ST. LOUIS, MO.

to this project during the school year 1927–28, beginning the latter part of September. Mr. Richtmann has had two years' experience in operating the infiltration testing equipment. Chester Braatz, a graduate student, has also become interested in this work in connection with his thesis, and during this school year will devote about half time in assisting Mr. Richtmann at no expense to either the Society or the University.

During the past summer vacation one test frame was built in the University shops. On account of a quarterly payment agreement with the Society, it was impossible to arrange to build all the frames at once on account of lack of funds. Furthermore, it

FIG. 4. TEST SET-UP FOR MEASURING INFILTRATION THROUGH WINDOWS IN SOUTHWESTERN BELL TELEPHONE BUILDING

seemed desirable to build one trial frame to experiment with before contracting for the building of the other frames. This move proved to be a wise one, as experience in handling this first frame and wall has resulted in changes of design which will not only make the new frames cheaper to build but will make it possible more easily to move them in and out of the testing machine.

The Technical Advisory Committee on Infiltration outlined the following program for research, at whatever points we might find it practicable to conduct the research:

(1) Brick wall with wood window and frame:

- (*a*) Determine frame leakage
- (*b*) Determine reduction in leakage by locking window
- (*c*) Determine reduction by applying storm sash—different methods of application
- (*d*) Determine leakage for different cracks and clearances, both locked and unlocked.

(2) 13-in. plain brick wall—joints not thoroughly slushed (as in practice, good grade of common brick).

(3) 13 in. plain brick wall—joints thoroughly slushed, good grade of common brick.

(4) 13-in. plain brick wall—joints not thoroughly slushed, extremely porous brick.

(5) 13 in. plain brick wall—joints not thoroughly slushed, glazed brick.

(6) Concrete walls—probably different mix and thickness.

After above walls are tested "plain," they may be either plastered or painted.

In November, 1927, the *Common Brick Manufacturers' Association* agreed to cooperate with the Society to the extent of $1500.00 in 1928 to help promote this project

of research on infiltration through various brick walls. Major L. B. Lent, engineer of that association, was to be appointed a member of the Technical Advisory Committee on Infiltration.

On November 22, Director Houghten and Major L. B. Lent visited Madison to discuss with Professor Larson the proposed cooperative tests on infiltration through walls, and after discussing the work in detail, and inspecting the testing equipment, the following program of tests was agreed upon, for the Madison Laboratory.

PROGRAM OF TESTS ON 13-IN. WALLS

Wall Number	Kind of Workmanship	Kind of Mortar	Kind of Brick
1	See description below		
2	Good	Cement or cement-lime	Hard
3	Good	Lime	Hard
4	Good	Cement or cement-lime	Porous
5	Poor	Cement or cement-lime	Hard
6	Poor	Lime	Porous

It was agreed that the mortars should be mixed in the following proportions:

CEMENT MORTAR—One of cement and three of sand by volume and enough water to make it workable.

LIME MORTAR—One of lime and three of sand by volume and enough water to make it workable.

CEMENT-LIME MORTAR—One of cement, one of lime, and six of sand by volume and enough water to make it workable.

All walls to be tested before plastering or painting. Tests to be repeated after plastering or after painting. It was the general opinion that tests should be made on 8 in. walls at a later date.

The tests on Wall No. 1 will be carried forward as listed in the original program except that the frame leakage will be determined before and after plastering the brick wall. The program on this wall is as follows:

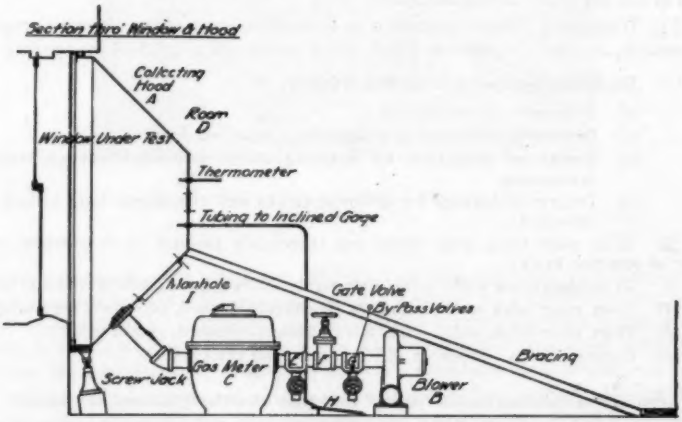

FIG. 5. APPARATUS USED FOR MEASURING INFILTRATION THROUGH WINDOWS

Wall No. 1—brick wall with wood window and frame.

(*a*) Determine frame leakage before and after plastering wall
(*b*) Determine reduction in leakage by locking windows
(*c*) Determine reduction by applying storm sash—different methods of application
(*d*) Determine leakage for different cracks and clearances, both locked and unlocked.

Present Status of Tests at Madison

Wall No. 1 was completed some time ago and has been allowed to dry out for about two months. Meanwhile the testing machine has been moved so as to make it more accessible to the moving of wall frames and numerous tests have been made to determine any possible source of leakage inherent in the machine itself. Tests have been started on Wall No. 1.

Working drawings have been made of improved wall frames and of a crane for moving the same. Bids have been called for and the contract has been let for five wall frames and the crane. The contractors have promised an early delivery and the frames and crane will no doubt be delivered and erected in the laboratory ready to receive the brickwork by the middle of January. Through the courtesy and cooperation of Major Lent, sample bricks have been sent us upon which tests are being made for porosity and compressive strength to aid in selecting bricks to conform with the testing program. When our selection has been made, Major Lent will furnish us with a sufficient number of brick of the proper grade to build the walls listed in the above-mentioned testing program.

We hope to be able to present the results of tests on Wall No. 1 at the summer meeting of the Society, and hope to present the final results of the tests on the other five walls at the winter meeting of the Society in 1929.

The Laboratory is to be congratulated on the securing of cooperation from such men as Professor Larson. To him is to be given credit for the first University cooperative agreement. He is showing continually a spirit of generosity in service, and of reliability in making his reports, technical and financial, which are an example and an inspiration to us all. The great University at Madison is backing him up to the extent that our dollars are much more than matched by the State of Wisconsin.

It is perhaps illuminating to know that the disposition of the University is to have all of its research along our lines handled through the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

In addition to the Laboratory tests which have been discussed in the preceding paragraphs, the Research Staff of the Society has recently completed a field study of the infiltration of air through plain and weatherstripped steel sash as actually set in the Southwestern Bell Telephone Building, a modern office building of the skyscraper type, located at St. Louis, Mo. Results of this work appear in the November JOURNAL of the Society, and have been reprinted in other technical magazines. This work was done under the immediate supervision of Director F. C. Houghten, and involved many difficulties which were finally overcome by the development of new methods and special types of testing equipment. (Figs. 3, 4 and 5.)

One set of apparatus, identical with the five sets used in the Southwestern Bell Telephone Building in St. Louis, was attached to a window in the Grand Central Palace

Building in New York as an exhibit during the Power Show. Besides serving as a very satisfactory exhibit in which a great many people were interested, data was actually collected on the window. This was a pivoted window, fairly loose and showed a very high leakage.

Committee on Pipe Sizes

H. M. HART, *Chairman*

SINCE the last summer meeting of the Society, the Laboratory has expended a considerable part of its efforts on pipe sizes, in developing tables for use in THE GUIDE. As a result of this effort, in cooperation with THE GUIDE Publication Committee and the *Heating and Piping Contractors' National Association*, the third chapter of THE GUIDE on Steam Heating Systems and Piping was developed. A considerable part of the Chapter is based directly upon the Laboratory's findings as reported at last summer's meeting and published in the September issue of the JOURNAL, and for the first time the Pipe Section of THE GUIDE represents a complete and consistent unit.

The Laboratory is now making a study of the capacity of branches to radiators for one- and two-pipe systems in cooperation with the Carnegie Institute of Technology. While progress is being made on this study, sufficient data is not yet available to present a report on this subject.

Special mention should be made of the devoted and unselfish work done in the development of these pipe-size tables by C. V. Haynes, a member of the committee, and by Mr. Houghten, who gave up part of his vacation to the service. It is interesting also to remark that much of the mathematical work on these pipe-size tables was done as a labor of love, by Mrs. Houghten, who is an expert mathematician.

Committee on Radiation

F. D. MENSING, *Chairman*

THIS committee has been acquiring information and studying radiator-testing laboratories. It is very likely that an equipment for testing radiation, possibly both direct and indirect types, will be built in 1928. There is not very much information on the subject available, and there are a great many different opinions among those who have tested radiators.

The paper in the December, 1927, JOURNAL sets forth some of the difficulties and offers some of the solutions.

Committee on Temperature, Humidity and Air Motion

W. H. CARRIER, *Chairman*

AN INVESTIGATION has been carried on in the psychrometric rooms at the Society's Research Laboratory to determine the rate of metabolism and the rate of evaporation from subjects under varying conditions of wet- and dry-bulb temperature and air movement. The object of this investigation was:

FIG. 6. EXTREMELY SENSITIVE BALANCE TO DETERMINE WEIGHT LOSS

1. To obtain a rational basis for ventilation requirements.
2. To determine the physiological reaction which occurs under these various

FIG. 7. METABOLISM TEST

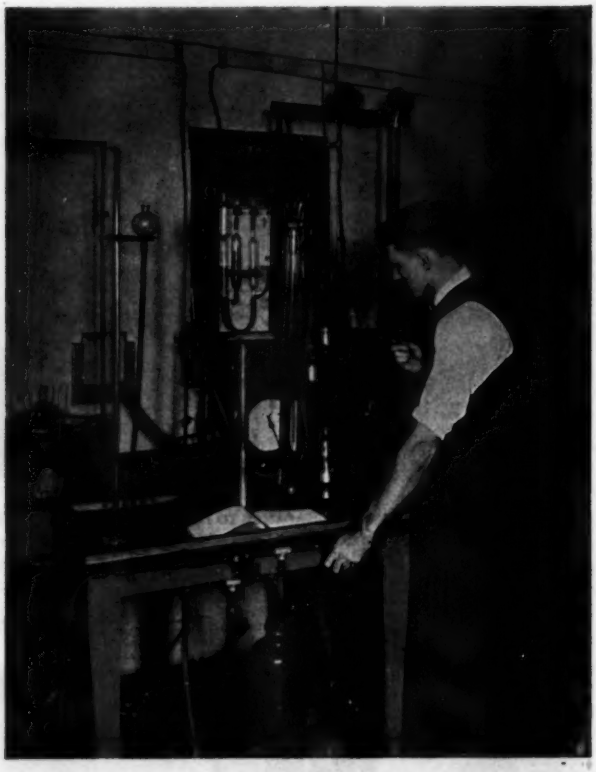

FIG. 8. APPARATUS FOR MEASURING, SAMPLING AND ANALYZING EXHALED BREATH

conditions and tie them up if possible with the sensation of comfort as indicated by the comfort lines.

As might have been anticipated from physical reasoning, it has been discovered that the sensible heat, that is, the heat given off by radiation and convection as sensible heat to the air and surrounding objects is a variable depending solely upon the variations between the average skin temperature and the temperature of the surroundings.

For any effective temperature it may be assumed, and it is indicated by experimental work, the skin temperature is reasonably constant so that for any effective temperature line, at least the amount of sensible heat given off, varies nearly directly as the difference between body temperature and dry-bulb room temperature. Since under these conditions metabolism also is constant, that is, the total amount of heat produced in the body is constant, and also since evaporation from the skin and lungs must also

make up the difference between the total heat produced in the body and that removed by radiation and convection as sensible heat, it necessarily follows that the total weight of evaporation from the body varies not with the wet-bulb temperature, as might be supposed, but inversely with the dry-bulb temperature. That is, as the dry-bulb temperature of the air increases the sensible heat given off decreases proportionately and the latent heat removed by evaporation increases correspondingly. Therefore, this evaporation from the body is seen to be controlled primarily by the dry-bulb temperature for any given effective temperature. This may seem somewhat surprising to many but the reason for this apparently is, in so far as the skin is concerned, the physiological control of evaporation is such as to regulate the amount of moisture given off to obtain

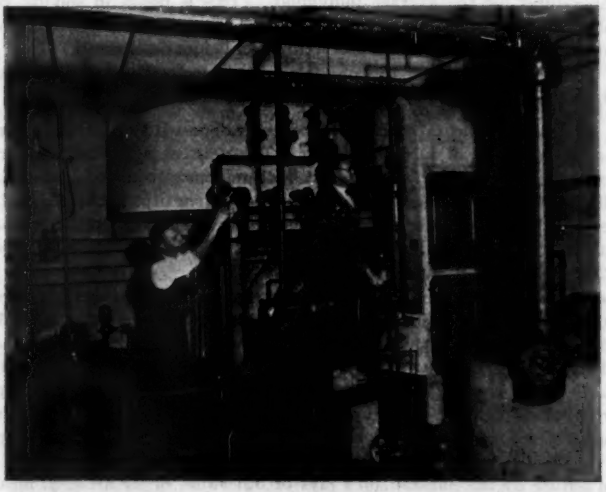

FIG. 9. AIR CONDITIONING EQUIPMENT USED AT LABORATORY

the heat balance independently and regardless of the evaporating power of the air. A still more remarkable fact determined, and which was contrary to our anticipation, was that there was but very little relative variation in the metabolism or in the total heat given off under various atmospheric conditions, especially in the neighborhood of the comfort zone. However, for extreme conditions on either side of the comfort zone the total heat given off by the body increased markedly. This would naturally be expected for the extreme temperatures below the comfort zone, but it also occurs in the extreme temperatures above the comfort zone. This latter effect undoubtedly was due to the extra effort of the circulatory and respiratory organs in their effort to maintain a temperature balance, and this extra effort undoubtedly was the cause of the increased metabolism and total heat produced. The sharp rise at this high effective temperature point is a pretty good indication of the breakdown of the physiological control system and occurs in effective temperature regions where it is probably im-

possible for human beings to exist permanently. If this is true, then this break in the total heat curve is a very clear indication of this danger-zone region. While this does not primarily interest engineers engaged in the ventilation of buildings, yet it is of primary importance to those who are called upon to ventilate hot work-rooms, mines, etc.

The facts which we have determined with a considerable degree of accuracy are:

1. The total amount of heat given off by the average individual.
2. The relation of the amount of heat given off to the body surface and weight of the individual, and the degree of variation that occurs in these factors between different individuals.
3. The relation of sensible to latent heat given off for various dry-bulb temperatures for the average individual. (This is useful in solving ventilation problems where temperature and humidity control, that is, effective temperature control, are desirable. These data were never before determined.)
4. The point where the physiological control of body temperature begins to break down.

All of this experimental work described was done with a view to determine the physiological reactions of subjects at rest. The next step will be to determine the physiological reactions of subjects at work with reference to metabolism and moisture given off; the work done being a definite measured quantity. It is believed that this last research will complete the series of temperature, humidity and air motion experiments necessary for determining some of the logical factors in heating, cooling and ventilation.

There remains one other series of experiments which it is hoped at some time to attempt, although the determination will prove much more difficult, and possibly too difficult for exact determination. One of the things really needed to determine in ventilation is the effect of so-called air purity upon the animal organism and, if possible, upon the human being. It is also necessary to determine if there is an appreciable effect from what might be termed devitalized air, or any beneficial effect from what might be termed vitalized air. By this expression it is not meant that any appreciable change in chemical constituents but only the ionizing effect which may be produced in air in nature by the natural sun's rays or otherwise, or by artificial means giving an equivalent effect. It is quite possible that there is in outdoor air subjected to the ultra-violet rays of the sun and other ionizing forces a property very analogous to vitamins in food which science has recently shown us may be simulated by exposure to the ultra-violet rays, either natural or artificial, in analagous manner. It may be pointed out that so-called ozonizing equipment undoubtedly has an ionizing effect on air apart from the production of ozone, which is an indication of extreme ionization of the oxygen. It is possible that effective ionization can be produced in this manner or some other means, as by treatment with ultra-violet light artificially, without any material production of ozone, which in excess is objectionable, and that there may really be beneficial physiological effects from the naturally ionized air of outdoors, or a corresponding artificially ionized air indoors. In other words, it may be found possible, through the cooperation of the ventilating engineers with the scientists to produce an indoor effect exactly as beneficial as outdoor effect if there is found to be any really essential or important difference physiologically. It is recommended that the Committee on Research and the Society obtain the cooperation of physical scientists and the medical profession.

Committee on Heat Transmission through Building Materials

L. A. HARDING, *Chairman*

THE Laboratory is continuing the research investigation of heat transmission through various types of building construction with the Nicholls heat flow meter. More data have been collected in the study to date than will be necessary probably in the future, for satisfactory determination of the desired constants. These additional observations were made in order that information might be gathered concerning such doubtful questions as the relation between heat flow and temperature change, wind velocity, heat capacity of the wall, sun effect, character of the surface and precipitation, and also to make possible a better understanding of the application of the Heat Flow Meter method of determining coefficients of total transmission, inside and outside surface transmission, and conductivity or conductance. (Fig. 10.)

With the large number of observations made in the various tests, more time is required for complete analysis of the data than for their collection, and this part of the work has been allowed to lag until sufficient data are available to warrant the establishment of sound conclusions. Most of the data so far collected have been only partially analyzed in order approximately to determine the coefficients. Minor corrections, for heat capacity and change of temperature of the construction under test and for averaging results of data collected over a greater period of time, may alter slightly some of the results given.

The data now available and their partial analysis indicate that the Nicholls heat flow meter gives consistent and accurate results for the inside surface transmission coefficients and the conductivity constant, if the wall is made up of a single homogeneous material, and that it gives the conductance (that is, the heat flow through the wall per unit of time with unit temperature difference between the two surfaces) of compound walls

FIG. 10. APPLICATION OF NICHOLLS HEAT FLOW METER

HEAT TRANSMISSION DATA*

Project	Date	Length of Test Days	Construction	Exposure	No. of Meters	C	K
Bureau of Mines	August, 1926	15	2¼" T. & G. pine, felt, 3/16" slate	South roof	1	0.36	1.25
				East roof			
				North roof	1		
			Plaster on wire netting	Ceiling	1	1.64	1.47
Bennet Lumber & Mfg. Co.	December, 1926	15	Barrett roof	Roof	1	0.46	1.25
			8" double shell, glazed tile, vert. air spaces	South wall	1	0.40	0.89
			Same as above but for 2nd floor	South wall	1	0.40	
Schenley Apts.	January, 1927	15	4" brick, 8" tile, plaster	North wall	2	0.30	1.30
			4" brick, 8" tile, plaster	East wall	2	0.34	0.80
Gammon's Lunchroom	February, 1927	11	4" brick, 8" backer header tile, plaster	West wall	1		1.30
			4" brick, 8" backer header tile, plaster	West wall	1		1.17
Schenley Apts.	January, 1927	15	Plaster, 3" pyrobar, plaster	Partition	1	0.87	
Webster Hall	February, 1927	10	4" brick, 5" tile, plaster	East wall	2	0.48	
			4" brick, 5" tile, plaster	North wall	2	0.48	
Laboratory	March, 1927	7	13" brick, plaster		1		
Hotel Schenley	March, 1927	8	4" brick, 8" tile, plaster	East wall	2		1.17
Oliver Bldg., Room 812	March, 1927	8	{1½" terra cotta, 19" brick, ½" cement,	North wall	2	0.20	1.41
Room 1607	March, 1927	7	{3" furring tile, plaster	North wall	2	0.19	1.05
Westinghouse Insulated	April, 1927	8	4" brick, 5" tile, ½" cement, 1½"corkboard, plaster		2	0.15	0.92
			2" corkboard, plaster	Ceiling	1	0.19	0.98
Westinghouse Uninsulated	April, 1927	8	4" brick, 5" tile, plaster		2	0.45	
			Lath, plaster	Ceiling	1	2.48	0.93
Laboratory	June, 1927	8	8" concrete slab No. 1, 1:2:5 mix		4	1.79	
Mine Safety Appliance Co.	August, 1927	21	Tar roofing, ½"–1" concrete, 3½"–4½" cinders,				
			1½" concrete	Flat roof	3		
			Slag covered roofing, 1¼" T. & G.	Flat roof	1	0.31	
W. A. Bode Co.	Sept., 1927	21	Concrete tile, 30 lb. paper, ⅞" sheathing	Hip roof	1	0.28	
					1	0.27	
Laboratory	November, 1927	3	8" concrete slab No. 1, 1:2:5 mix		4		
	November, 1927	4	8" concrete slab No. 2, 1:2:5 mix		4		
	December, 1927	5	8" concrete slab No. 2, 1:2:5 mix		4		

* Tentative values from partial analysis of available data collected with Nicholls heat flow meter.

FIG. 11. TABULATION OF HEAT TRANSMISSION DATA DEVELOPED BY A.S.H.&V.E. RESEARCH LABORATORY

The total transmission and outside surface transmission for any given outside conditions can be determined accurately. However, variable conditions affecting the outside surface of the wall, as wind velocity and direction, precipitation, sun effect and clear or cloudy sky, make it difficult, if not impossible satisfactorily to valuate these constants to the degree of accuracy desired, from data collected by this method.

It is hoped, however, that complete analysis of the mass of data available may make it possible to differentiate between the different variables and to establish the magnitude of the effect of each.

The fact that under certain conditions the direct radiation from the sun to the sur-

FIG. 12. SCHENLEY APARTMENTS WITH HOTEL IN FOREGROUND. VARIOUS WALLS IN THESE BUILDINGS WERE TESTED FOR CONDUCTIVITY, USING THE NICHOLLS HEAT METER

face of a roof has the effect of giving a negative outside surface transmission coefficient (that is, heat is transferred to the surface of the roof when the air above is at a lower temperature) gives some understanding of the difficulty encountered. (Fig. 10.)

The following table gives the types of construction studied at Pittsburgh to date, the buildings in which the study was made, the time over which data was collected, and tentative values for surface transmission and conductance coefficients resulting from a partial analysis of the data collected on some of the walls, ceilings and roofs. (Figs. 11 and 12.)

It is planned to spend more time in analyzing the data in hand so that final results can be published in the JOURNAL. A Laboratory report to be presented at the Annual Meeting gives data on heat flow through a concrete-tile roof, and through a cinder-fill roof in summer.

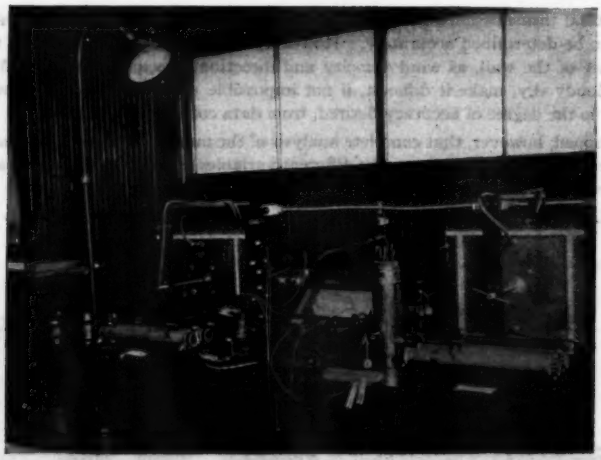

FIG. 13. APPARATUS AND INSTRUMENT FOR HOT PLATE METHOD OF TESTING HEAT TRANSMISSION THROUGH BUILDING MATERIALS, UNIVERSITY OF MINNESOTA

This paper will give conductance and inside surface transmission constants, the effect of variable outside conditions on the outside surface and total transmission constants, and the effect of sprinkling the roof and the color of the surface on the absorption and flow of heat.

The list of construction already studied covers the types agreed upon by the Committee at its meeting in Pittsburgh in October, 1926, as being those walls on which constants were most urgently needed.

The committee recently suggested additional types of constructions for study by the Laboratory, including the following:

1. 2 x 4 in. stud walls with $^{7}/_{8}$-in. sheathing, building paper, and drop siding outside, and with lath and plaster inside.
2. 2 x 4 in. stud walls with $^{7}/_{8}$-in. sheathing, building paper and brick veneer outside, and with lath and plaster inside.
3. Same as Nos. 1 and 2 with the addition of cork or other form of insulation.
4. 2 x 4 in. stud with stucco outside and lath and plaster inside.
5. 9-in. brick wall without plaster and with plaster and furring, lath and plaster inside.
6. 6-in. concrete wall.
7. Insulated roof with wood or felt shingles.
8. Insulated ceiling with unfinished attic.
9. Corrugated sheet steel wall.
10. Corrugated asbestos-protected metal wall.
11. Corrugated asbestos wall.
12. Steel roof, deck-insulation-felt roofing.
13. Determine in the Laboratory the surface coefficient (combined radiation and convection coefficient) for brick, concrete, plaster, wood and corrugated sheet steel for still air and for wind velocities up to 30 miles per hour.

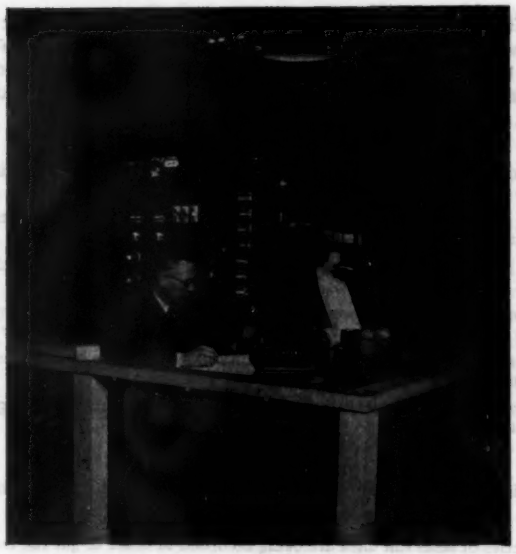

FIG. 14. EXTERNAL VIEW OF HOT BOX FOR TESTING HEAT TRANSMISSION THROUGH BUILDING MATERIALS, UNIVERSITY OF MINNESOTA

This new work is actively under way at the University of Minnesota, under Professor Rowley, and our cooperative Research Contract. One full-time man, A. B. Algren, M.E., and two half-time men, C. C. Carlson, M.E., and John Beal, Chemical Engineer, are devoted to this work, with considerable time being given by Frank A. Morris, assistant director of the experimental engineering Laboratories of the University of Minnesota. (Figs. 13 and 14.)

Two 12-in. standard hot plates and a standard double hot box have been built, these complying with the Society's code for testing building-insulating materials.

The box is built into one of the walls of the cold storage room in which temperatures may be maintained as low as 30 deg. below zero. The University is also furnishing instruments, such as type *K* potentiometers, watt meters, etc., needed as well as taking care of the expense of operating the refrigerating plant and other equipment. The Research Laboratory is furnishing a Nicholls heat meter which will be used in conjunction with the hot box. Thus the equipment is fairly complete for a thorough study of the whole problem of heat transmission through building materials.

The program to be followed is flexible and will be added to or changed as the work progresses. At present, several frame walls have been built both with and without insulation. These walls are being tested at temperatures ranging from 70 deg. fahr. to —10 deg. fahr., and also from 80 deg. fahr. to 0 deg. fahr. Some of the walls are also

being tested at higher mean temperatures in order to determine the effect of mean temperature range on the amount of heat transmitted. In the past, most of the work has been done at high mean temperatures, and probably many of the accepted results are higher than those which will be obtained at the lower ranges. The walls which have been built up, and which are at present being tested are as follows:

1. Studding 16 in. on centers with lath and plaster on the inside, sheathing, one thickness of building paper and lap siding on the outside.

2 The same as No. 1, except that an insulating blanket material one-half inch thick is added between the stud.

3. The same as No. 1, except that an insulating board is substituted for the sheathing.

4. Studding on 16 in. on centers with an insulation board and plaster on the inside surface and insulating board with paper and lap siding on the outer surface.

5. The same as No. 1, but with the exception that plaster board is used in place of lath and plaster.

6. The same as No. 4, with the addition of one-half inch insulating material between the studs.

In addition to these, some metal walls are being tested to determine the surface temperatures and the effect of insulating materials and roofing.

In this series of tests full data are being recorded in order to get the total heat transmission constant, the conductivity of the various materials and the surface constants. From these results, it will be possible to check the correctness of the present method for calculating the heat transmission for built-up wall sections. It will also be possible to substitute other insulating materials in place of those used and to obtain the transmission constants where the insulating materials are of a similar nature. A further series of walls contemplated are to be built up of hollow tile.

The U. S. Bureau of Standards is continuing its work with the guarded hot plate and has recently published a list of conductivities for various building insulating materials on the market.

The Engineering Experiment Station of Pennsylvania State College is continuing its study of heat transfer with the heat flow meter and new data on the subject was presented at the winter meeting of the *American Society of Mechanical Engineers.*

Another problem which is being investigated is the comparative accuracy of the hot plate and the hot box methods of determining insulating values. The conductivities of certain insulating materials are being checked by both methods. This will give a check on the accuracy of surface temperatures determined by the hot plate and the hot box methods. The effect of the thickness upon the conductivity as determined by the hot plate is also being investigated.

There are many fundamental problems which will bear investigation in this field and while many built-up wall sections are to be tested, it is the present plan to obtain sufficient data on each wall section and its component parts in order that the test will apply not only to the particular insulating material used in the wall, but also to other materials of similar properties.

Committee on Code for Testing Building Insulation

A. P. KRATZ, *Chairman*

THE committee for framing a code for the testing of heat transmission through building walls was appointed April 12, 1927. This committee framed a tentative code which was presented at the Semi-Annual Meeting at White Sulphur Springs, West Virginia, June 28 to 30, 1927. The tentative code has been published in the August, 1927 issue of the JOURNAL.

The committee held a joint meeting with a committee from the insulation manufacturers in Chicago, September 27, 1927. At this meeting the tentative code was discussed, and certain revisions suggested which met with the approval of the code committee. The committee has, accordingly, made such revisions, and now presents the code in form for final discussion and action by the Society at the winter meeting.

This committee holds the record for prompt and effective action, and having completed its work should now be discharged with our thanks and most beneficent memories, with the understanding, of course, that if we find need of revising this code we may ask the assistance of these men.

Committee on Air Cleaning Devices

F. B. ROWLEY, *Chairman*

THIS committee was first appointed by President Driscoll as a Committee to draw up a standard code for the testing of air filters. The Committee functioned as a committee of the Society for some time and as such made two preliminary reports, one at the Annual Meeting at St. Louis, and the other at the Semi-Annual Meeting at White Sulphur Springs. (Fig. 15.)

From the studies of the problem which the Committee made, it was evident that something more than a search of the literature was necessary in order to devise a proper code. It appeared that a considerable amount of research was necessary in order to determine such problems as the best and most practical method of measuring dust in the air, a method of producing a uniform consistent dust mixture and the selection of a

FIG. 15. EXPERIMENTAL ENGINEERING LABORATORIES, UNIVERSITY OF MINNESOTA

standard or of several standard dust determinators. While a great deal has been written on these subjects there is no uniformity of opinion which would lead to standardization. In fact, there seemed to be a wide variance in results obtained by the different methods. For these reasons the Committee was discharged as a Committee of the Society, and a new Committee was appointed as a Technical Advisory Committee of the Research Laboratory on Air Cleaning Devices. This committee was appointed at the Semi-Annual Meeting in June, 1927.

It has not been the aim of the Committee to devise new methods of testing for dust, but rather to try out the existing methods and to select those which are best adapted for the practical testing of filters. To accomplish this, it is necessary to set up apparatus by which dust can be mixed with air in as thoroughly a manner as possible, this dust then being cleaned from the air by commercial air filters and the quality of the air then being determined by the different types of dust determinators.

For the first part of the work, the Committee has confined its attention to the unit stationary type of dry air filters. These are the most easily handled and the data developed will apply to the self-cleaning type and also to the water-spray filters, both of which will be used in later experiments.

Efforts are being made to maintain uniform dust and air mixtures, but it may be necessary to determine the concentration not only by the amount of dust mixed, but also by some form of dust determinator. Different types of determinators are to be used, but as a start the Hill dust counter and the Anderson-Armspaugh determinator are being tried out. It is the hope of the Committee that several types of determinators may be calibrated, and the results correlated to such extent that relative values may be used for the different methods. It may be found that some counters will be practical in some fields and not in others.

The Committee recognizes also the problem of measuring different kinds of dust by the same method.

A dust which is, at present, being tried out on account of its uniformity is lycopodium powder. It is necessary to select some such dust as this in order first to calibrate the dust determinators.

Thus far the apparatus needed has been supplied free of cost by the various manufacturers, and in every case the spirit of cooperation and helpfulness has been excellent. Requests have not been made of all filter manufacturers for material, as it was not thought necessary to have a large variety of units until the preliminary work had been finished. At present, apparatus has been supplied as follows:

A No. 2 American Sirocco fan, direct-connected to a 220-volt, one-half horse power, direct current motor, by the American Blower Co.

Two Reed air filters with steam washing and drip tanks together with cleaning fluid, oil, etc., by the Reed Air Filter Co.

Air filter cell by the Duro Air Filter Co.

Offers have also been made by the Midwest and numerous other companies for apparatus which will be taken advantage of when needed.

A Hill dust counter is being supplied by Dr. E. Vernon Hill and an AA dust determinator has been furnished by the Research Laboratory.

This apparatus is now being assembled in the Experimental Engineering Laboratories of the University of Minnesota as follows:

FIG. 16. EXTERIOR OF NEW THERMAL LABORATORY, UNIVERSITY OF KENTUCKY

A 4 x 4 ft. dust mixing chamber is being provided from which the dusty air is carried by a 20-in. square pipe through a series of air straightening devices to an air filter. From the filter the dust is drawn through an orifice to measure the flow and then to the fan from which it is discharged. Openings are being provided on each side of the filter to obtain the sample of air for the desired test method. Pressure drop throughout the filters are measured by the inclined water gauge. The assembly of this apparatus is well

FIG. 17. GENERAL VIEW OF BOILER TESTING LABORATORY, UNIVERSITY OF KENTUCKY

under way and in a very short time initial data will be collected. The research work is being carried on as a part of the cooperative agreement between the Research Laboratory and the University of Minnesota.

Committee to Determine Maximum Boiler Output

F. PAUL ANDERSON, *Chairman*

THIS is the committee which is looking after the boiler testing work at the University of Kentucky. The best name for this committee was difficult to select. The principal immediate business of the committee is to check up, to prove and to criticise the proposed code for testing boilers to establish ratings.

The equipment at Lexington was assembled and put into effect with remarkable

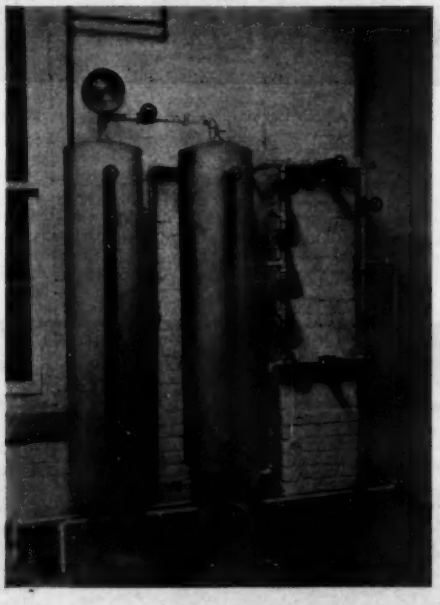

FIG. 18. MEASURING TANKS FOR FEED WATER, UNIVERSITY OF KENTUCKY

dispatch. Some of the results already indicated are covered in Professor O'Bannon's paper. (Figs. 16 and 17.)

The floor space occupied for boiler testing in the new Thermal Laboratory is 18 ft. by 67 ft. There is room for six boilers on the test floor at one time. An induced draft

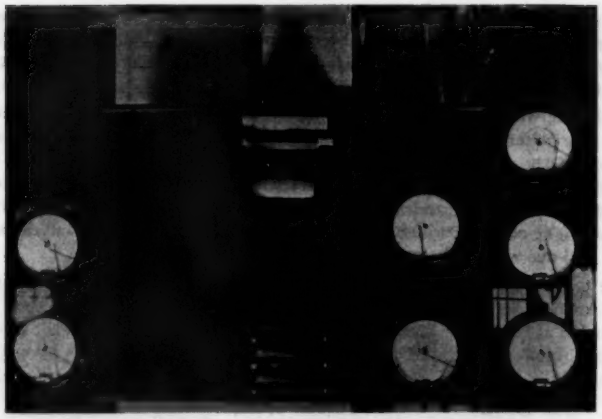

FIG. 19. RECORDING INSTRUMENT GAUGE BOARD FOR BOILER TESTS, UNIVERSITY OF KENTUCKY

fan connected to an 18-in. tile flue in a trench extending the length of the room furnishes the necessary draft. The steam outlets of the boilers are connected to an overhead main terminating in a condenser at one end of the room. The calibrated tanks for measuring feed water are in the opposite end of the room. An instrument panel, or gauge board, hangs from an overhead trolley and may be moved from one end of the row

FIG. 20. BOILER UNDER TEST. THIS SHOWS THE POSITION OF THE THERMOCOUPLES, STEAM SEPARATOR, AND BREECHING, ETC., UNIVERSITY OF KENTUCKY

of boilers to the other. Fixtures are provided for holding it rigidly in place when once moved into position for connecting the instruments to the boiler under test. Noting the variety of recording instruments it is apparent that the boiler virtually writes its own story of the test. (Fig. 18.)

Beginning with the feed water system, the source of supply is water from the city mains. The water enters the bottom of the measuring tanks, and compresses the air in the top of the tanks. The water in one tank is fed to the boiler while the other tank is being filled. A system of double valves, with the space between two adjacent valves relieved to the atmosphere when the valves are closed, prevents any error which otherwise might occur by water by-passing the tanks through leaky valves and getting into the feed line without being measured.

The temperature of the feed water is recorded by a recording thermometer, and a well is provided in the feed water line for a mercury-in-glass thermometer. The feed line branches at the boiler; one branch leads directly to the boiler, and the other goes to the boiler through an automatic boiler feeder. This feeder maintains a constant water level for a given load, and relieves the test crew of the necessity of regulating the feed valve.

A recording differential pressure gauge mounted on the instrument panel records the level of the water in the boiler. It shows the fluctuations due to boiling and to priming during the test as well as it supplies an impersonal record of the level at the start and finish of the test. (Fig. 19.)

The steam pressure is read from a mercury manometer at the boiler and is recorded by a recording pressure gauge on the instrument panel.

The steam leaving the boiler passes through a steam separator and then into the steam main. The separator drain is piped to a barrel resting on scales. The level of the water in the pocket of the separator is marked on the separator gauge glass at the beginning of the test and the water is blown down periodically during the test to the original mark and weight. The pipe, pipe fittings and separator are covered from the boiler outlet to a distance several inches beyond the separator.

There is a drip pocket at the bottom of the riser connection to the steam main. The condensate from this drip is let out through a valve into a bucket and weighed.

The gate valve in the connection to the steam main is regulated by hand to control the boiler steam pressure.

The steam main is a 4-in. pipe and is not covered. The end of the main branches through six 4 in. by 4 in. by $1^1/_4$ in.-tees into the six sections of the double pipe condenser. (Fig. 21.)

The double pipe return bends and tees which constitute essential parts of the condenser are the familiar water cooler fittings used largely in refrigeration plants. The inside pipe through which the steam and condensate flows is $1^1/_4$-in. brass. The outside pipe is 2-in. galvanized wrought iron. The cooling water flows through the annular space between the two pipes. The condenser is constructed on the counter-flow principle. The cooling water is supplied to each section from a 2-in. header at the bottom of the condenser, and leaves through a 2-in. header at the top. The condensate is collected in a 2-in. header which is vented to the atmosphere. The water is drained from the header through a 2-in. vertical pipe, in the bottom of which is a small orifice. A water gauge shows the height of water above the orifice. The maximum range of head

on the orifice is 40 in. of water. Different size orifices are provided for different rates of evaporation. The head on the orifice is recorded continuously by a recording pressure gauge mounted on the instrument panel. The rate of flow being proportional to the square root of the head on the orifice, changes in the rate of evaporation may be noted at any instant. The condensate leaving the orifice is caught in a funnel and delivered through directing valves to either one or the other of two tanks mounted on platform scales. There is a small gauge panel near the condenser on which are mounted indicating thermometers for the cooling water in and out, and also a two-pan recording thermometer which registers the outside temperature and the room temperature. The amount of cooling water used is regulated to keep the condensate temperature down to about 100

FIG. 21. OVERHEAD DOUBLE PIPE CONDENSER

deg. fahr. A continuous record of the condensate temperature is also obtained by means of a recording thermometer.

The double-pipe type of condenser was selected in order to eliminate the necessity of running leakage tests before each official boiler test, as would be required if the ordinary type of surface condenser were used. The usual test code demands a condenser leakage test preceding the test of the main equipment when the weight of the condensate from the condenser is one of the important items to be determined.

There are no joints between the cooling water space and the steam space. The double-pipe condenser is not offered as the ideal condenser, since it occupies considerable space and is not easily moved from one location to another.

It would not be difficult to modify the ordinary type of surface condenser to conform to the principle of no joints between water space and steam space. (Fig. 22.)

The coal is weighed in a box of about 1000-lb. capacity resting on platform scales. The coal is fired directly from this box into the furnace. A time-and-motion recorder

keeps account of the opening and closing of the fire doors. The frequency of attention required by the fire through the fire door is automatically registered as the test proceeds.

Three inclined tube draft gauges mounted on the instrument board give the draft in the ashpit, the furnace draft and the draft in the flue. The intensity of the flue draft is also continuously traced on the chart of a recording gage. (Fig. 23.)

A recording pyrometer with a range of 0 to 1500 deg. fahr., using iron-constantin thermocouples of No. 14 B. & S. gauge wire, is used for measuring the flue gas temperature.

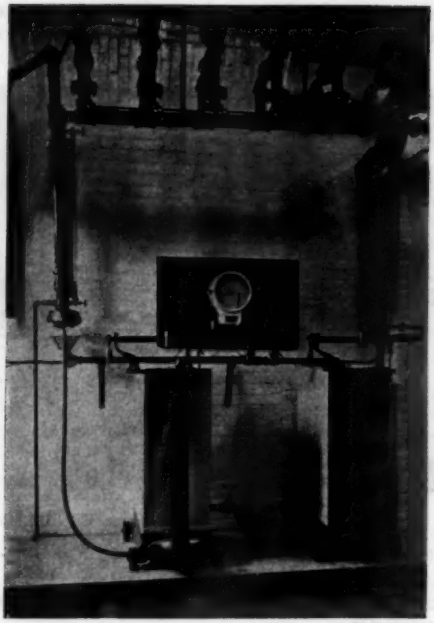

FIG. 22. WEIGHING TANKS FOR CONDENSATE

A combined carbon dioxide and carbon monoxide recorder is used in addition to the Orsat gas analyzer. A differential pressure recorder connected across an orifice in the flue furnishes information concerning the rate of flow of gases. The draft is regulated by varying a resistance in the main flue leading to the fan. The usual line of laboratory apparatus is available for special tests and for calibrating instruments.

While the somewhat complete autographic features of the laboratory stand out in the foregoing description, it should be pointed out that no elaborate array of apparatus or special devices can compensate for poor management or unskillful supervision of tests.

Familiarity with basic principles, experimental technique, and a proper recognition and appraisal of values are of prime importance.

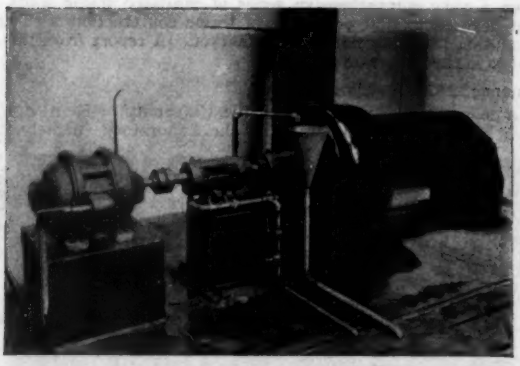

FIG. 23. INDUCED DRAFT EQUIPMENT FOR BOILER TESTING, UNIVERSITY OF KENTUCKY

A list of particular points upon which information is needed has been furnished to the University of Kentucky, for the benefit of the original code committee. It is surprising how many questions develop, as tests progress, as to code provisions.

The studies being conducted as to priming, to develop a satisfactory limit of moisture in steam, are especially illuminating and interesting.

In conclusion, it is suggested that the working rules of the Committee on Research remain as they are, very flexible. Technical advisory committees should be kept small and active, taking advantage of the opportunity thereby to interest and awaken non-members or quiet members of the Society.

Acknowledgment is made especially of the services to the Laboratory of Messrs. Houghten, the director, and Hutchinson, the secretary of the Society. I do not see how finer work could be done than that which these men have accomplished.

Respectfully submitted,

COMMITTEE ON RESEARCH
SAMUEL R. LEWIS, *Chairman*

Report of Research Laboratory Work in 1927

SINCE the last meeting of the Society, the work of the Laboratory has been greatly expanded through cooperation with a number of universities. Results of this cooperation make it apparent that a greatly expanded program of research in the field of heating and ventilation and its relation to the comfort and health of man may be had for the asking.

Through cooperation with the University of Minnesota, the new problem of studying air filters and cleaners with a view of developing a Code for Testing such devices was added to the Laboratory's program. The work is progressing satisfactorily, and we should obtain more concrete information on this very important subject in the near future.

Through cooperation with the University of Minnesota, the Laboratory's program on heat transmission through building construction has been enlarged. Professor Rowley is working on this subject with his guarded hot box and he is rapidly com-

pleting tests on a very comprehensive series of insulated frame walls. So far, the work has been devoted to different types of frame construction with and without a number of insulating materials now on the market. A report from this work can be looked forward to in the near future.

Boiler Performance and Its Relation to Rating

Through a cooperative agreement with the University of Kentucky, another new problem, which has long awaited attack by the Laboratory—namely, that of boiler

FIG. 1. EXHIBIT OF APPARATUS FOR MEASURING LEAKAGE OF AIR THROUGH WINDOWS AT POWER SHOW, GRAND CENTRAL PALACE BUILDING, NEW YORK

performance and its relation to rating—has been added to the program. A report on this subject by Prof. L. S. O'Bannon, who is carrying on the work, was presented at the Annual Meeting, and the paper, The Testing of Low Pressure Steam Heating Boilers, was published in the February, 1928 JOURNAL.

Infiltration through Various Types of Building Construction

The Laboratory's program on infiltration has been largely taken over by the University of Wisconsin through a cooperative agreement with that institution. By devoting a considerable part of their research activity to this one subject, it has been possible to build up facilities at the University which will greatly expedite the Laboratory's work on this subject. In this connection it has been made possible to build a number of walls and test and retest them alternately. Some of these walls will be

FIG. 2. COLLEGE OF INDUSTRIES BUILDING, CARNEGIE INSTITUTE OF TECHNOLOGY

made part of the outside exposed wall of the building so that between tests the effect of ordinary weather conditioning on infiltration through the wall may be observed. Professor Larson has this work in hand and we may look forward in the near future to valuable information on brick walls built with various grades of material and workmanship.

A study of infiltration through a couple of walls is being continued at Pittsburgh. Additional data have been collected on the effect of painting an unplastered brick wall. Tests on the standard frame wall (lap-siding, paper, sheathing, studding, wood, lath, plaster and wall paper) are now completed, and the lap-siding will be replaced by stucco. Final results of tests on these walls will be reported later.

The data collected in the investigation of infiltration through windows in the Southwestern Bell Telephone Building have been analyzed and a complete technical paper was published in the November, 1927 JOURNAL (p. 639). This report was also presented at the Annual Meeting.

A similar study of infiltration through windows in a modern building was

FIG. 3. HEATING LABORATORY, CARNEGIE INSTITUTE OF TECHNOLOGY WHERE THE PIPE-SIZE INVESTIGATION IS BEING CARRIED ON

made by the Laboratory in the Grand Central Palace, New York, during the Power Show. One set of apparatus used at the Southwestern Bell Telephone Building was applied to a window in the Grand Central Palace. This application served the purpose of a laboratory exhibit at the Power Show and at the same time, resulted in valuable data on infiltration through this type of window.

Fig. 1 shows the set-up and exhibit. A complete report on this subject will be published at a later date.

Radiation

While the Technical Advisory Committee on Radiation has been active during the past year, no work has been under way in the Laboratory. An attempt was made, however, to analyze the needs of this problem in a paper which appears in the December JOURNAL and which was presented at this meeting.

Thermal and Moisture Exchanges between the Human Body and the Atmosphere

This phase of the general problem of determining the relation between health, comfort and feeling of warmth of man and his atmospheric environment has been continued at the Laboratory and a completion of the study is in sight. A Laboratory report will be forth-coming in the near future.

Capacity of Pipe for Different Parts of a Steam Heating System

At the Semi-Annual Meeting of the Society, June, 1927, the Laboratory presented a final report on capacities of up-feed steam heating risers for one- and two-pipe systems (See September, 1927 JOURNAL, p. 545). Since that meeting a large part of the Laboratory's effort on the study of pipe sizes has been directed toward the development of practical tables based upon the Laboratory's findings. This work, in which the *Heating and Piping Contractors' National Association*, and the GUIDE committee cooperated with the Laboratory, has resulted in a completely revised set of tables in the Pipe Size Section of THE GUIDE. For the first time, this chapter of THE GUIDE appears as a consistent unit.

The Laboratory is continuing the pipe size study in cooperation with Professor Dibble's Department of the Carnegie Institute of Technology. A study is now being made of the capacity of radiator branches for one- and two-pipe systems.

Fig. 2 is a view of the College of Industries Building of Carnegie Institute of Technology and Fig. 3 shows the heating laboratory.

Respectfully submitted,

F. C. HOUGHTEN, *Director*.

A change in the By-Laws was unanimously adopted as follows:

Change in By-Laws

Article No. 2, Section 10 of the By-Laws reads as follows:

Any person having been elected to membership in the Society shall be promptly notified by the Secretary, whereupon he shall accept such election, subscribe to the Constitution, By-Laws and Rules of the Society and pay the initiation fee within three months after such notice of election shall have been sent him, or his election shall become void.

Be amended to read:

Any person having been elected to membership in the Society shall be promptly notified by the Secretary, whereupon he shall accept such election, subscribe to the Constitution and By-Laws and pay the amount of his dues within three months after such notice of election shall have been sent him, or his election shall become void. Failure to qualify within the time allowed will forfeit Initiation Fee.

Report of the 1927-28 Committee of the American Society of Heating and Ventilating Engineers on the Rating of Low Pressure Heating Boilers

JANUARY, 1928

AT THE Semi-Annual Meeting of the Society in June, 1927, the committee presented a report and a tentative code and asked that approval be delayed in order to give the committee time to discuss the proposals with those interested; and also to receive suggestions based on careful study of its provisions. At that time it was believed that six months would be sufficient and that a code for adoption could be submitted at this Annual Meeting. The committee has found, however, that it underestimated the inertia of the many interests it had to overcome, and considers it advisable to delay its final report till the 1928 Mid-Summer Meeting.

The committee does not consider that this postponement will mean a corresponding delay in putting the code into active use. The adoption of the code by the Society against the desires, or without the approval, of those who will have to apply it would be a mistaken policy; when it is recalled that the Society for many years has been periodically attempting to get the manufacturers to agree to a common method of listing the outputs and operating characteristics of their boilers, it is not surprising that there has been considerable inertia to overcome, and that six months were not sufficient for the committee to get in active cooperation with the representatives of other bodies, especially when that time included the summer and the vacation period.

It was natural that the committee, in its endeavor to obtain opinions, should seek the cooperation of the trade associations. The manufacturers and contractors who are not members of these associations were too many for the committee to approach individually but these had received the general invitations issued through the Society. The committee also acknowledges the assistance of the *Heating and Ventilating Magazine* which opened its columns to correspondence from its readers.

After the Semi-Annual Meeting requests were sent to the *Heating and Piping Contractors' National Association*, the *National Boiler and Radiator Manufacturers' Association*, and the *American Boiler Manufacturers' Association* that they appoint committees to meet with the Society's committee. There was considerable delay in this being done, so that the first meeting did not occur until October.

A meeting with a committee of the *National Boiler and Radiator Manufacturers Association* was held in New York on October 20. It was unfortunate that the committee we met with had not received authorization to speak for their Association, nor had it held any previous meeting. Its members, as individuals, acknowledged the necessity of having a common method of expressing the outputs and operating characteristics of heating boilers, but were not agreed on the sufficiency of the A.S.H.&V.E. 1927 tentative code, nor did they have another plan to substitute.

Your committee was disappointed in the results of this meeting, and felt that the Association had not sufficiently instructed its committee, nor had it taken steps to ensure that pre-consideration would be given to the subject to be discussed. It is believed, however, that a majority of the manufacturers who are members of that Association are desirous, individually, that a satisfactory solution of the problem may be arrived at so that uniformity in stating operating boiler characteristics may result.

Two meetings were held with a committee of the *Heating and Piping Contractors' National Association*. At the first on Nov. 8 it was agreed that the two committees would cooperate in studying the code of the Association and the proposals of the committee with a view of harmonizing them. In order to make this effective, a joint committee consisting of the two committees was formed, with Alfred Kellogg as Chairman.

The method of the *H. & P.C.N. Association* is based on obtaining, by tests, complete performance charts, and fixing the comparative rating from these, whereas the A.S.H.& V.E. committee proposals were limited to defining the allowable output at times of maximum demand, although its June 1927 report had suggested the additional minimum number of tests required to obtain complete catalogue data. A proposed enlarged code was therefore drawn up by your committee and discussed at a meeting of the combined committees on Dec. 7. A skeleton of this enlarged code is attached to this report.

The principles of this proposal were agreed to, except it was thought that two efficiency tests at 30 and 60 per cent of the rated load should be made and their values averaged to obtain a one-figure efficiency value. Discussion of details was deferred until your committee had completed its discussions with the manufacturers' committees and a proposed final code had been prepared.

Your committee appreciates the cooperative spirit shown by the *Heating and Piping Contractors' National Association* and believes that their experience in collecting and interpreting boiler data during the past four years will make their support of the Society's work very valuable.

On Dec. 9 a meeting was held with a committee of the *American Boiler Manufacturers' Association*. Previous to this meeting the committee of the Association had submitted a report discussing the Society's tentative 1927 code, and a counter discussion of this report had been sent to the *A.B.M.A.*

It is well known that makers of steel boilers give catalogue ratings which at least more nearly correspond to installed radiation than do the values used for the cast iron type. On the other hand, they have no agreed-upon common method of determining the values they assign. The reports referred to above were mainly concerned with discussing whether the rating outputs should correspond to normal or maximum demand; the *A.B.M.A.* committee were not convinced that the proposal to standardize the latter was correct, but it is believed that they will accept it if the code as a whole is satisfactory to other interests.

At the meeting on Dec. 9, H. Starr Barnum, as chairman of the committee of the *A.B.M.A.*, stated that they were authorized to speak for the members of their Association. An outline of the proposed extension of the code was presented and was fully discussed. No definite agreement was reached but the committee of the *A.B.M.A.* made some tentative suggestions for changes which they asked the Rating Committee to consider. They urged that the term rating be eliminated and output with some adjective designation be substituted. They also thought it desirable that more tests than those proposed be called for, but were not prepared to prove definitely the need or show the purpose of such tests.

Your committee is fully in sympathy with the desire to eliminate the word rating and believes that its use can be avoided. It was, however, thought better to retain its use in this present report as it was so freely used in the previous one.

Your committee has noted in its discussions with other committees and with individuals that they have difficulty in conceiving a plan for rating except in terms of a method of selection based upon the load conditions to be met with in practice. The viewpoint of your committee has been that the part which (what it has termed) rating output would play in selection was apparent, and that therefore discussions were simplified by the elimination of the consideration of selection. The rating output will play just the same part in selecting a boiler as the horse power capacities do in the choosing of motors. Having determined the maximum demand load of the building to be heated, all boilers listed in the manufacturer's catalog as having a rating output of approximately the computed maximum demand requirement will be possibilities, and their other operating characteristics can be considered and compared. The rating output will therefore act as a kind of catalog index by which the boilers which can be compared for the final selection are reduced to comparatively few in number.

It has also been the committee's belief that the correct procedure was that an agreement on a uniform method of stating the operating characteristics of boilers, and a code to cover it, was necessary before work on a code of selection was begun. The proposal

that the boiler code be enlarged to include definitions of all operating characteristics and the minimum test necessary for their determination has so far changed the viewpoint of the committee, that the formulation of codes for chimneys and for boiler selection has been given consideration as likely to prove of greater value to the heating interests than would the presentation of a single code for rating only.

The conception is that the code for chimneys would go further than covering their construction and would in effect establish the engineering rules by which their size should be determined. The laws of chimney action and the factors of safety which should be used in computing the correct size are independent of the boiler and undoubtedly injustices can be inflicted on purchasers of boilers if the same method of computation is not used.

The committee does not believe it necessary to lengthen this report by outlining what it considers to be the unsettled features of the final code for boiler performance data, nor the pro and con arguments that can be advanced. Adequate discussion on such features take considerable time. Its desire is that the code, as finally submitted to the Society for approval, shall have previously received the endorsement of the manufacturers and contractors. This consummation is of far greater importance than a discussion of minor technical details.

Enlarged Code

The principles of the enlarged code which the committee has drawn up to serve as a basis for discussion are shown by the extracts from it which are appended to this report. The committee has not adopted it and knows that there are a number of its suggestions which are debatable.

The main objectives underlying the proposal is to so closely specify and to control the testing that manufacturers may have equal opportunity to obtain results, and that these may be legitimately comparable with results obtained by others; also to call for the minimum number of tests involving the minimum cost to the manufacturers and yet will give all the necessary data required for catalogs.

It is to be understood that these proposals will not debar the manufacturer from making the full number of tests necessary to plot a complete performance chart should he so desire, but they necessarily assume that manufacturers' catalogues will all give the data obtained by the tests.

Objections have been raised to stating efficiency in any form, this objection being based on the well-known discrepancies which result when the same boiler is tested by different crews. The committee believes that this is largely due to the fact that while test specifications have controlled the way test data are to be measured, yet they have not sufficiently controlled the firing, the damper regulation and the general conduct of the test.

The need for, or usefulness of, a priming test has also been questioned, and as an alternative, it has been suggested that the output—as measured by smokehood temperature—should be increased to a fixed per cent above that of the rated output, and that no serious priming shall occur. There is very little published data on priming, and no established agreement among manufacturers as to what is meant by the water line of a boiler.

In conclusion the Committee would urge that the manufacturers recognize that the drawing up of this code is an engineering task and that they should give their engineers full freedom to so discuss and consider it. The sales and commercial questions that are involved can be considered after engineering features have been settled.

Submitted by the Committee,

ALFRED KELLOGG, *Chairman*
F. C. HOUGHTEN P. NICHOLLS
S. R. LEWIS L. E. SEELEY

Code for the Performance Data of Low Pressure Solid Fuel Steam-Heating Boilers

General

THIS code defines the minimum performance data that shall be determined for low pressure steam heating boilers using solid fuel, and specifies the tests required and how they shall be conducted.

Three types of tests are specified:

Rating test, to determine rating output, smokehood draft and flue gas temperature, if lower than the standard, covered in Section I.

Efficiency test, to determine the overall thermal efficiency at a defined fraction of the rating output, covered in Section II.

Priming test, to determine the output at a defined quantity of priming, covered in Section III.

There shall be a *rating test* and an *efficiency test* with each fuel that it is desired to have data on. With most boilers the type of fuel will not materially affect the priming characteristics and usually it will be sufficient to make that test with one fuel.

SECTION I—RATING TEST

Purpose

The purpose of giving low pressure heating boilers rating values, as are defined by this code, is limited to that of permitting comparisons between their outputs with specified maximum allowable operating characteristics.

The code will remain essentially as it is, but a number of changes in detail will be necessary.

SECTION II—EFFICIENCY TEST

Purpose

The purpose of the Efficiency Test of this code is to determine a value for the overall thermal efficiency of a low pressure steam heating boiler, which will be representative of the boiler's operation under service conditions, and which will be comparable with the values similarly determined for other boilers.

Definition

The test to obtain the efficiency shall fulfill the following limiting conditions:

(1) The average output per hour during the whole test period shall not be less than 45 per cent or greater than 55 per cent of the rated output.

(2) The fuel used shall be the same in kind and size as previously used for the same boiler in determining its rating output.

(3) The quantity of fuel fired at any one firing period shall be equal to that which is or will be used in computing the length of firing periods.

(4) When burning anthracite or coke the method of arranging the residue of unburnt fuel and of firing the fresh charge shall be that recommended or specified by the manufacturer for each fuel. The methods used for bituminous fuels shall be those recommended by the manufacturer as tending to reduce the smoke produced to a minimum.

(5) When burning anthracite or coke no changes shall be made during a firing period in the settings of the ashpit, firing door or other air control dampers. The only damper adjustment permissible is to the stack damper which can be changed if it is necessary to do so to bring the average output within the specified range.

(6) When burning bituminous coals the ashpit, firing door or other air control dampers may be changed once in each firing period, provided all such changes are made at one time; the fuel bed may also be given attention once in each firing period provided this be done at the same time as the air control dampers are adjusted. The stack damper can be changed if it is necessary to do so to bring the average rate of output within the specified range.

An abbreviated efficiency test specification, alternative to that of the A.S.H. & V.E. 1923 code is given.

SECTION III—PRIMING TEST

Purpose

The purpose of determining at what rate of output a low pressure steam heating boiler primes excesssively is to establish the ratio between this output and the rating output.

Definition

The priming output of a boiler is that found under the following limitations:

(1) The height of water in the boiler as indicated by the gauge glass shall be A inches above the normal water level specified by the manufacturer.

(2) The moisture in the steam as determined by steam separator during any consecutive 15 minutes, while operating under approximately constant rate of output, shall not exceed B per cent of the steam delivered.

Here follows the priming test specification.

DISCUSSION

PRESIDENT ANDERSON: Sometime ago we organized a Committee for the preparation of a Code for the Rating of Low Pressure Boilers with Alfred Kellogg, Boston, as chairman. I would like to ask Mr. Kellogg to present the report of the Committee.

ALFRED KELLOGG: The chairman wishes to further emphasize certain features of the report presented by this committee at this time, particularly the word *inertia*. The several associations with whom the committee has held conferences, have in the past adhered quite naturally to preconceived ideas of the various factors upon which their scheme of rating was based, and considering the many years of their adherence to such methods of rating boilers, perhaps we should not be surprised that considerable time is required in the readjustment necessary to bring the various interests into harmony. The Committee feels that it has made considerable progress in bringing about a measure of cooperation of the several associations, and has received a marked degree of support and consideration for which it makes due acknowledgment at this time.

Another obstacle to rapid progress in the work of the committee is the rather firm conviction held by all interested—both manufacturers, contractors and some engineers also, that *boiler rating* and *boiler selection* are one and the same thing, or at least that they must be considered together.

A little thought, however, will make it clear that the function of a boiler is to heat water to a certain degree, or to evaporate a certain amount of water into steam as the case may be, and this function has no definite relation per se to variations in weather conditions or to building construction, which, along with other variables, quite definitely fixes the load upon which *selection* so largely depends. The words *rating* amd *selection* may not be the best to use in describing the conditions to be met, but they are nevertheless pretty well understood by engineers and the trade.

The committee feels, therefore, that owing to the deep-rooted notion connecting so intimately boiler rating and selection for purposes of boiler installation, that it might be well to enlarge the scope of the work of this committee, in order that a *Code*

of Selection also may be included in its final report. This will be brought to the attention of the meeting later on.

The report also outlines in a general way the program of the committee for its future work.

Briefly, it is felt that the technical representatives of the manufacturers would do well to meet together and put their cards on the table, to the end that we may all see just how apart we really are at this moment. To this end also, the commercial departments of the boiler manufacturers should be urged to compose their differences with their technical force or advisers, to the end that this vexatious question of boiler rating or selection, or whatever you wish to call it, may be started on the road to a logical settlement. If there is the *will* to end the present chaos, the *way* will be readily enough found. The committee has in mind inviting the technical representatives of the various manufacturers to what may be termed a public hearing on the subject, to be held in some convenient city sometime in March next.

Of this, however, Mr. Nicholls will speak later on in the meeting.

W. T. JONES: In line with Mr. Kellogg's suggestion and so that the Committee won't be handicapped in working with these other organizations, I would like to make a motion that this report be accepted, that the title of the Committee on Rating Low Pressure Boilers be changed to the Committee on Rating and Selection of Low Pressure Boilers and that the Committee be authorized, if it so desires, to increase its own membership.

The motion was seconded by Mr. Mensing.

PRESIDENT ANDERSON: I would like to see this report accepted as a progress presentation and some evidence given here that we are ready to make a permanent committee out of this particular effective body because these men have been doing some excellent work and it would be desirable to give them full time in which to accomplish their labors.

MR. JONES: I would like to include that with the motion, Mr. President, then—that the committee's report be accepted as one of progress and that the committee be continued.

S. A. JELLETT: I would like to get that entirely clear. I am not a boiler manufacturer, as you know, but what effect would that have on our relationship at the present time until this whole code is developed, the naming by the committee of different makes of boilers for different purposes. It seems to me we are mixing the commercial side there too much with the technical side. I really don't believe we have reached the point where this committee can name particular makes of boilers to meet particular conditions. When I say makes I mean manufacturers. There is a trade question there that ought not to intrude on the work of this committee at the present time. We may reach the millenium when they will be ready to agree that certain makes of boilers are designed for certain work and should be so used, but I don't think we have yet reached it.

PRESIDENT ANDERSON: That is a question that might have an infinite number of answers.

MR. KELLOGG: In answering Mr. Jellett's remarks, perhaps I neglected to state that I feel that the boiler manufacturers are more anxious that a *Code of Selection* be formulated than is the committee. The committee has quite a job cut out for it. As to the inter-relation of the engineering and commercial side. Were it not for commercial considerations, the question of technical selection could be settled in 20 minutes, but when the commercial angle is such a prominent feature, this committee would not set itself up as being competent to ignore it. We must consider the practical side of the application of any *Code of Rating* to that of disposal of product, and it can be done if a *Code of Rating* serves to bring out the characteristics of all the types of boilers on the market. That will mean that some boilers will have to be relegated to the scrap heap. It means again, the survival of the fittest.

R. V. FROST: I wonder if this Committee will not be of greater value to the industry if it is made a boiler selection committee rather than a rating committee, for the reason that at the present time no one seems to have a very clear idea of how a boiler should be selected. It is left up to the consumer, although the manufacturer in a great many cases gives a great deal of data on the performance of his boilers, he will not publicly nor in writing in catalog data tell how that boiler shall be selected.

If the committee as an independent body can outline to the industry or to the trade rather how a boiler can be selected on uniform lines, I think the value of the committee would be very much increased.

F. D. MENSING: I think the work could be simplified if instead of rating boilers the committee was empowered to work out factors to aid in the selection of boilers. I think we all labor under the difficulty in the heating and ventilating field of not having factors of safety. I would suggest that Mr. Jones be given the opportunity to write up his motion and present it a little later when he has had the time to clarify just the motion as now put. We never really have time to frame a motion of this character on the floor and I think it would be a good idea if the motion was withdrawn to be presented a little later in the session. However, that is merely a suggestion.

I propose an amendment to Mr. Jones' motion that he be given time to prepare a motion and submit it to the body. I will offer it as a substitute.

The motion was not seconded.

PROF. F. B. ROWLEY: It is not just clear what the motion is. I would like to have it repeated so that I know definitely what we are voting on.

PRESIDENT ANDERSON: The motion that was made provides that this report be accepted, that the committee be continued and that the name of the committee be changed to the Committee on the Rating and Selection of Low-Pressure Heating Boilers.

S. R. LEWIS: It seems to me there is no need of any great detailed refinement of that motion, so long as the committee understands that its duty shall be to tell how the proposed code, which we hope will give the maximum output, shall be used practically. That is really what we are after. It seems that a great many people would grasp the meaning of this code more readily if we could understand how, when a boiler has been rated on its maximum output a man may select the size boiler for

a given sized duty. The committee, I think, can be trusted to develop the details of how that shall be done, and this is really the purpose of the motion, and the details of how the motion is worded are not of any great moment.

MR. KELLOGG: To smooth out any misunderstanding any one may have in regard to this matter, might I say that Mr. Mensing has merely put in different words exactly the idea advanced by Mr. Jones and explained somewhat in detail by Mr. Lewis. We are all working toward the same thing. It is, in other words, a move to provide for boiler selection for purposes of installation, derived from a rating code which this committee was appointed to prepare.

We have found, as previously stated, much difficulty in persuading the average man to separate the question of boiler rating from boiler selection, but whenever, we have had a chance to sit around a table and talk with those interested, they have always seen our point of view, but the few men that we are likely to meet in person are not going to have a great leavening influence on the 35,000 steamfitters for whom this work is being attempted.

MR. JELLETT: The wording there used was the selection of the boiler. If he means selection of a type of boiler, it will be different.

PRESIDENT ANDERSON: I think I can clear this matter up. Mr. Kellogg's committee was designated to develop a code for the rating and selection of low pressure boilers. This Committee does not have power to act or to put into effect any practice for this Society. After all it must come back to this Society for approval and all interests are safeguarded by requiring this committee to report their findings to the Society for final modification or approval. It seems to me that the present name of the committee does not indicate just exactly what this committee may find it necessary to do when it tackles the problem of selection as coordinated with the question of rating.

MR. FROST: Mr. Mensing's motion included the acceptance of the Committee's report. In that case, then, the discussion of the report is in order at this time. I would like to say a few words in regard to that. While I do not speak as a representative of a manufacturer or of a body of manufacturers, I am going to speak in the interest of the manufacturers, from their standpoint. Mr. Kellogg and the Committee have used the word *inertia* in speaking of the attitude of the manufacturers. I have had about 20 years' experience in heating work, and the great part of that time has been with the manufacturer. So that I know very much his attitude in regard to rating a boiler. While I am not representing a manufacturer at the present time, I think that he should be allowed a just viewpoint or that his viewpoint be placed correctly before the Society.

PRESIDENT ANDERSON: Mr. Frost, may I interrupt you. I think I can clear your mind on this subject. As I take it, this report is simply accepted as a progress report. Nothing final. There is nothing in this report that becomes now the official act of the Society, but we are merely accepting this report as a progress document.

MR. FROST: Well, then, what I have started to speak upon is perfectly in order. I want to clear up some of the points the committee mentioned in their report.

Quoting from the report, "It is recalled that the Society for many years has been periodically attempting to get the manufacturers to agree to a common method of listing the outputs and operating characteristics of their boilers. It is not surprising that there has been considerable inertia to overcome." As far as the manufacturer is concerned, he has been more of a live wire within his own circle on the question of rating than any other body in the industry. The heating and piping contractors a few years ago started the movement for a uniform rating of boilers, and their work, I believe, has had a great influence in getting a definite principle expressed upon which the manufacturers could work. The manufacturers as a result have taken the work of the heating and piping contractors and built upon it, using that as a foundation. The result is that now several manufacturers are furnishing to the industry data on the performance of their boilers which they would otherwise not have thought possible to give to the public to be used in the proper way. In fact, I was speaking with one manufacturer this morning and he said that 12 years ago they gave that information to the public and it was not used. There are at the present time to my mind at least four manufacturers who are giving these data freely in catalog data or when requested.

Then, the report of the Committee refers to the meeting with the *National Boiler and Radiator Manufacturers Association* October 20. It is stated here that the committee representing the manufacturers did not offer another plan to substitute and that they did not agree on the A.S.H.&V.E. code. The only objection that was offered to the A.S.H.&V.E. code at that time was on temperature limitation, but they did express the opinion that it would be more to the interest of all concerned if complete performance data were furnished. I don't think that the Code Committee can consider that the boiler and radiator manufacturers organization through that committee did not offer another plan to substitute. In fact, that meeting has had an effect upon the ideas of the committee as far as changing the viewpoint of the committee, for they make this statement—"that the formulation of codes for chimney and boiler selection have been given consideration as likely to prove of greater value to the heating interest than would the presentation of the single code for rating only. I think that is just exactly the idea of the manufacturers. I think that by enlarging the committee as we suggest now or enlarging the scope of the committee to cover selection, we will obtain really what the industry is looking for.

The Committee makes another statement. "It is desired that the code as finally submitted to the Society for approval shall have previously received the endorsement of the manufacturers and contractors." That is the only way we can get a working code. If it cannot be accepted by the manufacturers, of what use is it? The manufacturer is ready to go along with the Society. There is no doubt about that. I think the Code Committee can feel that they have the cooperation of the manufacturers in the final outcome.

MR. JONES: To explain my motion a little, as I heard Mr. Kellogg's report as being one of progess and asking for a little further time, the only suggestion that I noted was that the scope of the committee be enlarged to clarify the situation which was agreeable, as I understood, it, to the other association working with this Society. We know the members of this committee—Kellogg, Lewis, Houghten, Nicholls and Seeley. I think we can safely leave with that committee just the

word "selection." They know what to do as far as factors go and I think that they will bring out something that will clarify the situation immensely and do so without complicating the motion by telling them how to do it.

MR. KELLOGG: I think it is not improbable that there is a good representation present of all the organizations with which this committee has endeavored to cooperate, and I may add, with quite a measurable degree of success. It would therefore seem desirable that representatives of these associations if possible, make a presentation to this meeting of the attitude of their respective organizations so far as they have authority to speak. Our meeting with the Committee of the *National Radiator and Boiler Manufacturers' Association* to which Mr. Frost referred, we thought made very distinct progress which corroborates something the present speaker touched on a while ago. That is this: that it is not only the heating contractor who wants a *Code of Selection* to apply to a boiler rating code, but the manufacturers themselves want it. They want the solution of the chimney, the pick-up and all the other variable factors included in something comprehensive that will be of value to the entire heating industry. I certainly hope the representatives of the *National Radiator and Boiler Manufacturers Association*, the *Heating and Piping Contractors National Association* and the *American Boiler Manufacturers Association* will speak upon this subject before a vote is taken.

HOMER ADDAMS: In response to this invitation of Mr. Kellogg, my interest is that of the *American Boiler Manufacturers Association* as chairman of the Heating Boiler Division. Our industry includes nearly all the steel boiler builders in America who build for the great power stations, isolated plants and heating boilers also, and who have all the time acted in a way to arrive at precision and accuracy, so as to attain the most solid and sound foundation. Steel heating boilers have therefore been made by an industry that is building a hundred million dollar product annually, and they have always tried to be faithful to the highest achievements and the adoption of the highest manufacturing and performance standards and requirements. Naturally we are not conscious of any lack of response or lack of meeting your Committee's expectations. I am certainly confident that if there is any appearance of inertia to your Committee it is just because of the great, long, thorough, precise life that the industry has lived in and worked in and therefore does not move at a tick of the watch, but must go their own old way which has been thorough and sure and in a way they can collectively agree on.

Our industry has no objection whatever to this Code, but based on an understanding of all that we know of our products and all we have tried to acquire about our products in these years and through close cooperation by all the boiler builders, we comprehend that making this Code for rating low pressure boilers and applying the same depends on thorough and comprehensive knowledge, the united support of all that are interested, such as manufacturers, architects and engineers, contractors, owners, etc., and possibly also a guide to aid in the selection of such heating boilers for the different and widely varying uses that they are put to.

My view is that the two great considerations for this committee is to make sure of the cooperation by the interests that will have to apply to this Code, and that a reasonably sure guide be also available to the same sources to aid them in the selection of boilers that will function right under the varying conditions.

I think our industry will cooperate whole-heartedly with your committee and will follow just as far as it is for the good of the product and the user, for we, like the engineers and the architects, benefit alike from the same results.

H. M. HART: Speaking as a member of the Boiler Output Committee of the *Heating and Piping Contractors National Association*, we have spent several years with this problem. Due to the very broad range of conditions under which heating boilers are asked to function, we have purposely avoided the term rating on a boiler. We have developed what we consider a very good method for the manufacturer to present to the engineer or contractor a complete picture of the performance of his boiler under practical conditions of operations. So that the engineer, knowing as he should the conditions that he has to meet, can without question pick a boiler that will fulfil those conditions. We have felt that if a manufacturer simply published a single rating on a boiler under one condition of operation, that was not sufficient for the engineer to meet the various conditions that he finds in practice. We have found that the manufacturer has expressed himself as being in full accord with our ideas and we have now in our files a great many performance charts which give the full picture of boilers. The question of a uniform rule for the selection of a boiler, which merely means arriving at the total load, the maximum output that the boiler will be required to meet, as well as the most efficient boiler that can be selected to meet the condition of operation, has not been fully developed. This idea of giving the performance of the boiler is perhaps somewhat new with us and we were waiting until we had a comprehensive picture of these performance charts before we finally adopted a uniform method of selection. We are in accord with this idea of developing a method of selection of boilers from a performance chart. We are rather doubtful that a single rating on a boiler will be of sufficient importance to apply that formula. However, we are not hidebound on the question. If we can be shown that a single rating at some point on a performance chart is sufficient to give an engineer a method of selection, we will be glad to accept it.

Therefore, we are in favor of the proposed motion that the scope of the committee be enlarged and that the committee be continued and we have been invited to cooperate with this committee and we are glad to do so and will continue to do so so long as they care to have us, with the hope that the solution of this intricate problem will be met. We have been told by a very prominent man that nothing is impossible and I agree; I believe that the question will be solved. I believe that we will have the whole-hearted support and cooperation of the boiler manufacturers, because we are all seeking one goal. The manufacturer necessarily wants to have satisfied customers and the contractor the same, the engineer the same. So I don't see any reason why we can't work together and arrive at a satisfactory conclusion.

PERCY NICHOLLS: I should like to say a word as an enlargement of Mr. Kellogg's mention of a public hearing. The committee has reached the stage where it has a large accumulation of arguments and discussions on all phases of this subject, and finally a decision has to be reached and the final code drawn up.

The committee believes that previous to this decision there should be a public hearing, but because the rating code is a question of testing boilers it is therefore an engineering problem, and the associations and manufacturers should be represented by their engineers. It will in reality be a conference with the engineers, and

out of that conference should come the final code which we will submit to the Society.

It is proposed to hold this meeting at the end of March or beginning of April, and previous to it the committee hopes to submit to the delegates details of the points to be discussed and thus give them time to prepare for it.

MR. KELLOGG: In bringing this discussion to a close, I will briefly state that the word *inertia* has been fairly well defined. It must not be understood, however, that is was used in the progress report in any sense as implying *obstruction*. The meaning attached to the word as understood by the Committee has been very clearly defined by Mr. Addams.

In reply to Mr. Hart, it may be said that the committee from the beginning of its work has been and now is, in sympathy with the aims of the Boiler Output Committee of the *Heating and Piping Contractors National Association*, and it must be kept in mind that the work of the Committee on the Rating of Low Pressure Boilers of this Society in no way conflicts with the work of the sister society.

We, of course, know that the complete performance charts and data requested of the manufacturers by the Boiler Output Committee will afford the *trained* engineer full information for boiler selection, and there is nothing in the proposed code of this Society that would negative the publication of all desirable information of value to the prospective buyer; in fact, the draft of the tentative code presented at the June, 1927 meeting of the Society expressly invited the presentation in manufacturers' catalogs of data more complete than that covered by the Code.

The committee has felt, however, that its much simpler and more direct code requirements would better serve the needs of the 35,000 odd steamfitters and plumbers, constituting as they do, the vast majority of the boiler buying public, than the more involved charts and formulae, however valuable the latter may be to the thousand or two trained engineers. By all means, let us have both if we can obtain them.

PROGRAM—34TH ANNUAL MEETING

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

HOTEL PENNSYLVANIA, NEW YORK

Monday, January 23rd

10:30 A.M. Council Meeting
11:00 A.M. Committee on Research
Nominating Committee
Other Technical Committees

Monday, January 23rd, 1:30 p.m.

Greetings by President F. Paul Anderson
Report of Tellers of Election
Testing of Boilers and Radiators—Dr. C. W. Brabbée
Test Methods for Radiators, F. C. Houghten and S. R. Lewis
Discussion—Prof. E. H. Lockwood
Report of Council

Monday, January 23rd

4–6 P.M. Tea Dance, Hotel Pennsylvania
6:00 P.M. Past-Presidents' Dinner

Monday, January 23rd, 8:00 p.m.

Coordinated Research Session
Addresses:

S. R. Lewis, Chairman, A.S.H.&V.E. Committee on Research
Dr. F. W. Stratton, Pres., Massachusetts Institute of Technology
H. Leigh Whitelaw, American Gas Association

Tuesday, January 24th, 10:00 a.m.

Report of Committee on Research—S. R. Lewis, Chairman
Report of Director of Research Laboratory—F. C. Houghten
Code for Testing Air Cleaning Devices—Prof. F. B. Rowley
Practical Ventilation for Schoolrooms—S. R. Lewis
Effects of Ventilation on the Health of School Children—T. J. Duffield
First Principles in Unit Ventilation—W. R. McCornack

Tuesday, January 24th, 2:00 p.m.

Factory Heating and Ventilating Session:

Report of Committee on Increase of Membership—C. V. Haynes
Report of Secretary—A. V. Hutchinson
Report of Committee on Heating and Ventilating Garages—O. N. Walther
What Will the Engineer Choose—Heating Only or Air Conditioning for the Modern Plant?—H. P. Gant
Airation of Industrial Buildings—W. C. Randall
Natural Ventilation of Farm Buildings—Prof. F. L. Fairbanks
Report of the Finance Committee—Thornton Lewis

Tuesday, January 24th, 7:00 p.m.

Annual Dinner and Dance
Presentation of Past-President's Emblem to F. Paul Anderson
Address on Benjamin Franklin—Hon. A. O. Stanley, former U. S. Senator

Wednesday, January 25th, 10:00 a.m.

Some Studies of Corrosion in Return Lines of Steam Heating Systems—F. N. Speller
Code for Rating Low Pressure Heating Boilers—Alfred Kellogg
Relationship between Output and Operating Characteristics in Tests of Low Pressure Steam Heating Boilers—P. Nicholls
The Testing of Low Pressure Heating Boilers—Prof. L. S. O'Bannon

Wednesday, January 25th, 2:00 p.m.

Standard Test Code for Heat Transmission through Walls—A. P. Kratz
Utility Requirements for Hospital Buildings—Prof. G. L. Larson
Value of Building Insulation to Reduce Heat Losses—E. N. Sanbern
Economic Thickness of Insulation for Building Walls—M. S. Wunderlich
Extended Surface Radiation—Charles S. Sage

Wednesday, January 25th, 2:00 p.m.

2:00 P.M. Ladies attend Roxy Theatre Performance

Thursday, January 26th, 10:00 a.m.

Report of the Guide Publication Committee—Perry West
Practical Results of Ventilating the Holland Tunnel—Ole Singstad
Saving Heat in Skyscrapers—F. C. Houghten and M. E. O'Connell
Installation of Officers

Thursday, January 26th, 2:00 p.m.

2:30 P.M. Inspection of Holland Tunnel
3:00 P.M. Inspection of Brabbée Laboratory. Train leaves Grand Central Station

1:35 P.M. Harlem Division, N. Y. C. R.
2:09 P.M. Arrive at Mt. Vernon, New York; buses will convey members to Brabbée Laboratory
2:15 P.M. Luncheon will be served; the inspection will begin immediately after luncheon and at its conclusion members can make the return trip, leaving Mt. Vernon at 4:29 P.M.

Friday, January 27th, 9:00 a.m.

8:30 A.M. Council Meeting

COMMITTEE ON ARRANGEMENTS

H. B. Hedges, *General Chairman*

Russell Donnelly, *Chairman*, Hotels
Alfred Engle, *Chairman*, Entertainment
C. W. Stewart, *Chairman*, Ladies
W. J. Osborn, *Chairman*, Publicity
G. A. Dornheim, *Chairman*, Finance
R. A. Wolff, *Ex-Officio*

SOCIETY OFFICERS AND COUNCIL

President.....F. Paul Anderson, Lexington, Ky.
First Vice-President.....A. C. Willard, Urbana, Ill.
Second Vice-President.....Thornton Lewis, Philadelphia, Pa.
Treasurer.....W. E. Gillham, Kansas City, Mo.
Secretary.....A. V. Hutchinson, New York, N. Y.

COUNCIL

F. Paul Anderson, *Chairman*
A. C. Willard, *Vice-Chairman*

One Year	*Two Years*	*Three Years*
H. H. Angus	J. J. Kissick	W. H. Carrier
W. H. Driscoll	E. B. Langenberg	C. V. Haynes
Roswell Farnham	J. F. McIntire	John Howatt
H. H. Fielding	H. Lee Moore	W. T. Jones
F. B. Rowley		

No. 788

TEST METHODS FOR RADIATORS AND BOILERS

By C. W. Brabbée, New York, N. Y.
MEMBER

AT SEVERAL meetings of the Society[1] the author emphasized the idea of testing radiators, not by the method of condensation only, but also by a comparative method based upon the useful heat output of radiators. For the purpose of giving a clear résumé of the developments up to the present, the most important steps in this venture are repeated briefly.

Fig. 1 shows one room *R* used for human occupancy with all sides surrounded by well-heated spaces. In this room a person will feel entirely comfortable and no means of heat is needed. But the condition changes if hall No. 1 is taken away and replaced with outside air of zero temperature, as shown in Fig. 2. A person in this room will cool off quickly on the side of the body nearest the window and there will then be the necessity for a heater. This can, as shown in Fig. 3, be a vertical pipe heating the surrounding air, which will move up to the ceiling, or it can be, as shown in Fig 4, a shallow panel placed under the window and stretched out over the length of the whole outside wall. Assume that both heaters have 10 lb. of condensation per hour in steady state. Nevertheless, the panel system (Fig. 4) gives more comfort than the vertical pipe (Fig. 3), which is quite in accord with the general rule that warm feet and cool head are necessary for healthy, and even more so for ailing or aged people, and this is fundamentally the important point. The purpose of a radiator is not to have a certain amount of square feet of iron or a certain number of pounds of condensation, but to produce comfort for human beings.

In the Journal of the Society, November, 1925 and November, 1926, there are published the experimental and mathematical proceedings necessary to arrive at practical results, from which reports the following is taken:

In two test rooms (Fig. 5) of exactly the same construction and heat loss, both set up in a large room which is always kept at freezing point, the radiators are installed under exactly the same conditions and supplied with the same kind of steam. One of the radiators is standard and is kept unchanged during all tests; the other heater is the one to be tested. Its number of sections are selected in such a way that the temperatures measured near the center of the room and 1.5 ft. from

[1] Heating Effect of Radiators, Journal A.S.H.&V.E., Nov., 1925, Mar., 1926 and Mar., 1927.
Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

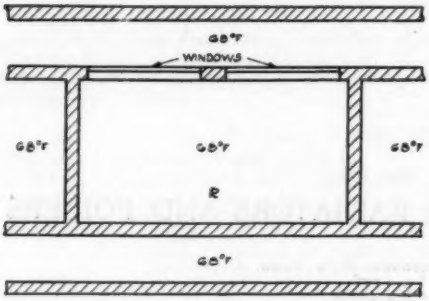

FIG. 1. COMFORT CONDITIONS IN A ROOM SURROUNDED ON ALL SIDES BY ROOMS OF 68 DEG. FAHR.

the floor are the same, in which case both radiators will secure equivalent comfort for human beings. More than 300 radiators have been tested in this way and it is pointed out that the calculation itself is simple, as shown in the aforementioned publication.

Even if this arbitrary but practical arrangement should be changed somewhat, the fact remains that herewith was devised a new and comparative method of testing radiators with a view to their function for assuring human comfort. A new definition appeared on the horizon and can be stated as follows:

Whereas, up to the present, that radiator was considered best which had the highest coefficient, *i. e.*, the highest condensation, the new method gives the greater value to that radiator which affords maximum comfort with minimum condensation, *i. e.*, minimum material and fuel cost.

Some important discoveries along the new line may be recalled. For instance, it has been stated that a certain radiator *Y* installed beneath the window, the radiator having 33.4 sq. ft. actual heating surface with 7.9 lb. per hr. condensation in steady state, gave more comfort than another radiator of 67.5 sq. ft. actual heating surface with 16.3 lb. per hr. condensation in steady state, the latter radiator being placed on the rear wall (Fig. 6).

In a further test it was found that 90.0 sq. ft. of a certain type of radiator similar to that shown in Fig. 7, with 25.8 lb. per hr. condensation in steady state, gave

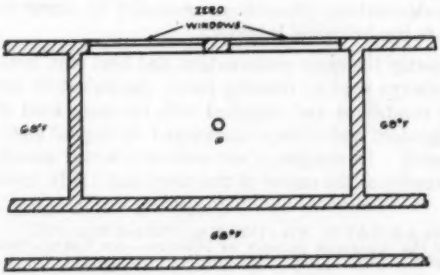

FIG. 2. COMFORT CONDITIONS IN A ROOM SIMILAR TO FIG. 1 BUT WITH ZERO WEATHER ON ONE OUTSIDE WALL

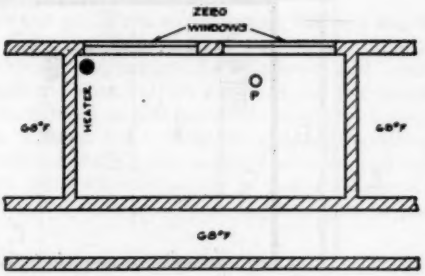

FIG. 3. COMFORT CONDITIONS IN A ROOM WITH ONE OUTSIDE WALL AND A VERTICAL PIPE IN AN OUTSIDE CORNER

more comfort than 126.0 sq. ft. and 32 lb. per hr. condensation in steady state of normal radiators, in which case both heaters were placed underneath the window. The explanation of these and similar surprising results was found in the temperature on the ceiling. With radiators distributing their total output, as far as possible, into the lower parts of the room, the ceiling temperature is 10 deg. fahr. and more lower, whereby the comfort conditions are improved and a decrease in expenses indicated. The fact that the temperature near the ceiling is much lower is very important but is disregarded when radiators are tested and rated by condensation only.

From the examples mentioned and a great many more one can see that the new revelation works in the direction of more comfort with less money, an important improvement in the service engineers give to the public. As the lighting industry was given the right start by establishing the principle that that electric bulb is best which gives the maximum light with minimum watt consumption, so our art must be pursued in the new direction. One must concentrate on the designing of radiators which will give maximum effect with minimum expense. Such a new definition certainly influences designing, testing, rating, estimating and installing of all kinds of heaters for buildings.

Testing Domestic Boilers

A frequently used test equipment for testing domestic boilers is shown in Fig. 8. Boiler *a*, with its water line *b* is connected through pipe *c* to a tank *d* on a scale and

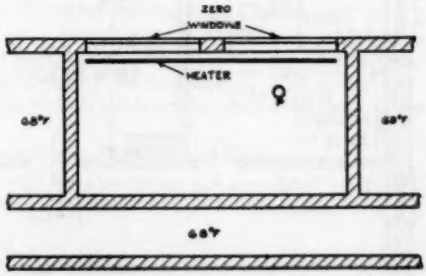

FIG. 4. COMFORT CONDITIONS IN A ROOM WITH ONE OUTSIDE WALL AND A FLAT HEATER STRETCHED OUT ALONG THIS WALL

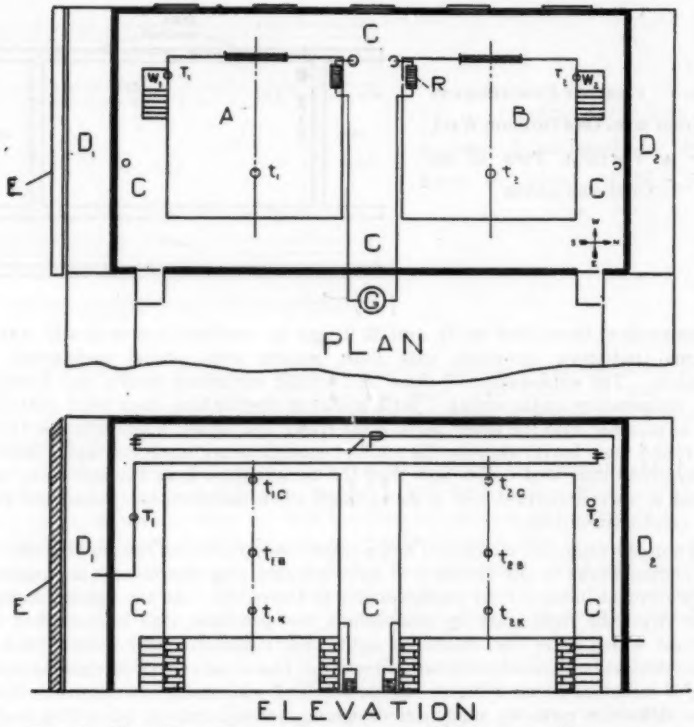

FIG. 5. TWO TEST ROOMS EQUIPPED FOR COMPARATIVE TESTING OF RADIATORS

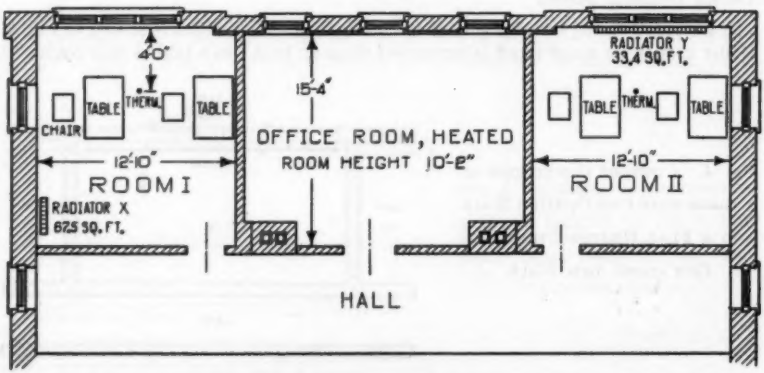

FIG. 6. COMPARISON OF A THIN RADIATOR UNDERNEATH THE WINDOW AND A NORMAL RADIATOR IN AN INSIDE CORNER

occasionally fed with water through line *e*. When a test begins, valves *g* and *h* are closed, the water line *b* in the boiler and the weight of the water in tank *d* are carefully noted. In running the test the water line falls lower and lower until it is necessary to refill from tank *d*. Then valve *h* is opened and feed water slowly admitted from *d*. This is done more or less frequently until the desired end of the test is near. Then the boiler is fed a little above its original water line *b*, valve *h* is closed and the operation of the boiler proceeds until the original water line *b* is reached. The weight of the water remaining in tank *d* is observed and the difference in weights between the start and finish of test taken as the evaporated water quantity.

This procedure is somewhat complicated if, during the test, the water contained in tank *d* is not sufficient and a refilling with water is necessary. Then a careful check of the additional water weight has to be made.

The disadvantages of this method are:

1. The boiler is fed at certain intervals, with cold water, a procedure not happening in practical operation.

2. The exact observation of the water line in a boiler under operation is difficult and quite unreliable if quickly steaming boilers are tested, needing a constant feeding.

3. If the boiler develops wet steam, the lost weight in tank *d* is by no means a measure for the evaporated water.

4. Therefore, a water separator *k* is inserted in the boiler's exhaust line, on the function of which the test results depend.

5. The insulation loss of the exhaust pipe has to be taken into consideration.

6. The whole procedure requires a great deal of careful weighing and can be useless if only one single error occurs in weighing.

7. For long operation tests which run days and nights such a method is tiresome and relies on human work, which is not free from error.

However, on boilers with small combustion fluctuations as, for instance, gas boilers, the described method is satisfactory when the necessary care is given and the operators are skilled.

A simpler method and, at the same time, one of greater accuracy in the author's opinion, is depicted in Fig. 9. The boiler *a* delivers, through line *b*, steam to condenser *c*, the condensate returning to boiler *a* by means of pipe *r*. In the condenser *c* the steam is condensed by water coming from an overflow tank *f* and running through pipes *g* and *h* to a weighing scale *k*, where its quantity is measured. The temperature of the incoming water is recorded by thermometer t_1; the temperatures of the outgoing water by thermometer t_2; the steam temperature by thermometer t_3; and the temperature of the return condensate by thermometer t_4.

The method has among others two important advantages which are as follows:

1. All heat units actually delivered by the boiler are measured by means of the condenser, entirely independent of all errors in water line, steam pressure, wet steam etc.[1]

[1] The heat loss of the pipes is determined by previous tests.

2. The boiler is under actual working conditions and, therefore, practical results are obtained. *d* is a water separator in steam line *b*, which, in connection with tank *e*, shows the overthrown water, making a calorimeter unnecessary. The whole procedure is entirely automatic, controlled by the regulator of the boiler and adaptable for studying constant or changeable boiler loads.

The quantity of the cooling water is uniform because it comes from the overflow tank *f*. The entrance temperature of this water is constant because it is

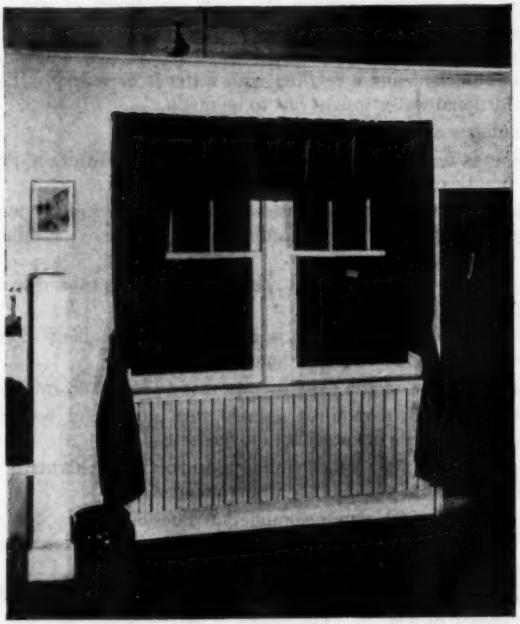

FIG. 7 FLAT RADIATORS PLACED UNDERNEATH THE WINDOW

water of a temperature practically unchanged during the test. The boiler output is, therefore, determined by the temperatures of the outgoing water alone. This being recorded, one knows the boiler's load at all times without making any weighing of the water and can, therefore, follow up the boiler's operation very closely. It would even be possible to scale the range of the thermometer t_2 in terms of boiler rating.

Each test checks in itself. The average water quantity multiplied by the average temperature difference between incoming and outgoing water gives, under normal conditions and with practically sufficient accuracy, the direct efficiency of the boiler, if compared with the heat value and the amount of the fuel used.

On the other hand, all losses can be followed very closely. There are measured and recorded the stack gas temperatures and the losses due to incomplete combustion, further the heat loss of the boiler's external surface and, finally, the losses by combustible in the residue and soot. This enables one to determine the indirect efficiency of the boiler if the chemical analysis of the fuel is known. Both values, direct and indirect efficiency, must check if the test has run long enough

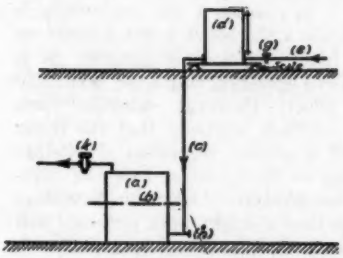

FIG. 8. USUAL BOILER TEST EQUIPMENT

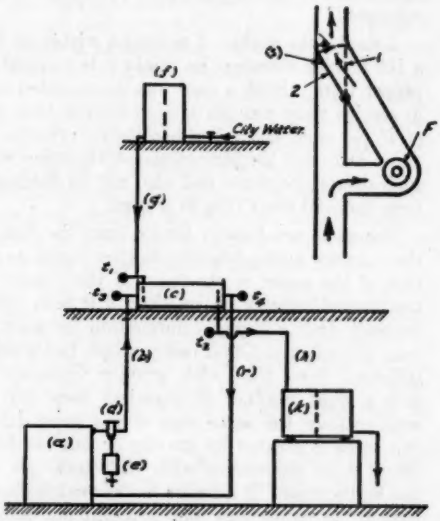

FIG. 9. NEW BOILER TEST EQUIPMENT

and the amount of coal burned is measured exactly. No test is accepted if the results differ more than ±2 per cent. In former years this method was made more accurate by placing the whole boiler on a scale, enabling us to follow up the fuel burned in certain periods, but this complicates the test very considerably and was found not necessary for practical purposes.

The tests run, very often, for days and nights, only a night watchman being present after office hours. He knows nothing about the test operation and is just acting as a normal and by no means exceptionally good fireman. In the morning the data are taken off the charts and the test is figured in a comparatively short time.

Three details have to be taken care of in the proper manner to obtain good test results:

1. The relation between the water contents of the boiler on the one side and pipes and condensers on the other must be within certain limits.
2. The insulation loss of the test installation has to be determined by previous tests, and

3. The thermometers have to be inserted in such a way that they indicate the average water temperature.

There is one more important point to be discussed. Everybody agrees that the chimney is to the boiler what the motor is to a car. More comprehensively expressed, it means that the best boiler is helpless with a bad chimney and a poor draft. In fact, the draft is the originator of the boiler's performance; why then, with that knowledge, are boilers tested in summer and winter and test results compared?

A final item is this: if a person wishes to test a 20,000 sq. ft. boiler requiring a 100 ft. high chimney, he thinks it is necessary to erect a 100 ft. chimney to make proper tests. Such a case was investigated and when the chimney was first put in service there was an outside temperature of 95 deg. fahr., a relative humidity of 75 per cent, and a low barometric pressure. All this together resulted in such a low draft that the performance of the boiler was entirely unsatisfactory. To avoid such disappointments and also not to damage the landscape around the laboratory, induced draft (Fig 9) is used.

The gases are directly drawn from the chimney through a fan *F* and back into the chimney again, whereby shutter *S* acts as a regulator, in addition to the variation of the speed of the fan. If the shutter is in position 1 the combustion is maintained entirely by gravity; if it is in position 2 the boiler works entirely on induced draft. Every combination between both conditions is possible. It is easy to understand that many people feel a boiler's operation with a fan is entirely different from that with gravity chimney effect. However, scientific facts and a great number of practical tests will convince anybody that the boiler acts entirely the same way if the same draft is applied, regardless of whether this draft is created by gravity or fan, as long as in the latter case the regulation is in accordance with the stack gas temperature. Only one restriction has to be made: If a boiler has revertible flues then it might work perfectly well with a fan equipment, but it might not properly start in actual operation with a gravity chimney effect. In this case, special care must be taken and the performance of the boiler studied in two parts, namely, for starting and running conditions. The former has to be observed with natural draft, for the latter the induced draft equipment can be used.

DISCUSSION

E. H. LOCKWOOD (WRITTEN): The suggestion has been made that radiators should be rated according to useful output, or ability to heat a room, rather than by the older method of total heat output. This idea first came to my attention during the discussion of Prof. Emswiler's paper, published in the JOURNAL, October, 1918, where it was stated that two radiators of different type, occupying the same position in the room, produced the same room temperature with differences in condensation from 15 to 25 per cent. The results were presented without explanation, although their paradoxical nature was recognized and commented on.

Dr. Brabbée has recently reported similar figures, where two different radiators, in the same position in the room, have given equal comfort with differences in

condensation of over 20 per cent. In this case the greater heat output was explained by the higher ceiling temperature maintained when one radiator was used.

R. V. Frost has reported similar results, showing that the total heat output of radiators is not always a true index of their ability to heat a room.

It will be of interest to discover how widely similar results have been found by other experimenters. I have to admit, in my case at least, no such differences have been noted. My observation has been that differences in useful heat output have been roughly proportional to the total heat output of the radiator. Measurement of useful heat output from a radiator is an exceedingly difficult task, and this fact makes me reluctant to make positive statements about it.

An estimate of difference in total heat output from radiators with same useful heat output may be made in general terms as follows: Suppose two buildings with rooms of identical number, size, exposure, both having same atmospheric surroundings. The first building is heated with radiators of high efficiency maintaining a low ceiling temperature. The second building is heated with radiators of poor efficiency maintaining a ceiling temperature 10 deg. fahr. higher than the first building. The installed radiation is such that an average temperature of 70 deg. fahr. up to the breathing line is kept in each room of both buildings.

Under these assumptions, the heat loss from the outside walls from floor to breathing line will be the same for both buildings since indoor and outdoor temperatures will be the same. The heat loss from outside walls from breathing line to ceiling will be greater in the second building, owing to higher inside temperatures. An estimate of the heat loss may be made from the average temperature difference, assuming 70 deg. fahr. room temperature for first building and 75 deg. fahr. in second, with 20 deg. fahr. outside temperature.

The temperature differences will be in the order of 50 and 55 deg. fahr., and the heat loss may be assumed in the same ratio, or 10 per cent greater in the second building. This heat loss relates only to the walls above the breathing line, or to only one half the total wall surface. It follows that the total heat loss due to higher ceiling temperature might be about 5 per cent greater, and the condensate from the less efficient radiators might be increased by this amount.

My conclusion is that useful and total heat outputs are probably in about the same proportion, but useful heat output is almost impossible of direct measurement. It follows that total heat output affords the most practical way to rate radiators, using the condensation method which presents few experimental difficulties.

F. C. HOUGHTEN: We should congratulate ourselves as well as Dr. Brabbée upon receiving the results of his careful study. Dr. Brabbée presents a unique method of testing which gives comparative values for two different radiators. Very interesting data are presented showing how one radiator under the conditions of the test does the same amount of work in heating a room as does another with about half as much steam. This is one of the most important questions before the heating industry at this time.

While Dr. Brabbée shows that one radiator does the same amount of effective heating as another, with only half as much heat, I do not believe that we can accept without further proof that this is a fundamental characteristic of the radiator

itself. We must consider whether it is not a characteristic of the room in which the radiator was tested as well as of the radiator. This thought was very well expressed by Mr. Mensing the other night when he stated that up to date we have been testing rooms rather than radiators.

I am wondering whether these two radiators tested in rooms of different design might not show quite different results. It is quite possible and even probable that the results could be reversed by picking two rooms of particular design as regards height of ceiling, floor area, heat loss from the walls, position of the radiator in relation to exposure and other factors.

This same question of greater efficiency in heating has been pointed out by a number of investigators. Work at the University of Illinois shows that the efficiency of heating by means of a warm air furnace is somewhat a function of the method of bringing the warm air into the room and its temperature and velocity.

Thornton Lewis has shown that with various types of unit heaters, heating efficiency depends upon the point of admission, direction of projection and velocity of the warm air entering the room from the unit heater.

R. V. Frost has shown that results similar to those found by Dr. Brabbée can be had from an enclosed radiator which emits most of its heat by convection which is entirely the reverse of the radiator which Dr. Brabbée has studied and which emits heat largely by direct radiation.

This all brings us to the consideration of whether or not we can at this time jump to the conclusion that these results are entirely characteristic of the radiator or whether we must not spend considerably more time investigating the subject as regards different types and designs of rooms.

R. C. BOLSINGER: Will Dr. Brabbée give us his thought on the question, human comfort, when using a radiator of the slab type as shown in his paper, particularly the comfort derived by the person in the room on account of the radiator being placed under the window, eliminating the radiation through the window from the human body? Will he also explain conditions with the slab type of radiator, using the radiant effect, telling whether or not that would cause a milder heat than high temperature of air circulating in the room?

W. H. CARRIER: I want to emphasize what Mr. Houghten said. My thoughts were running along the same line. I would like to ask Dr. Brabbée what results were obtained in the room that was tested by placing the same radiator in different positions in the room. That would answer, I think, very well the difference in efficiency as a characteristic of a radiator and the difference of efficiency as characteristic of a location. I think that all of us can recognize that the efficiency of location is of prime importance in laying out radiation or any other type of heat distribution.

I have in mind a particular case in a factory where they were very anxious not to have any drafts and they wanted to cool the building in summer and heat it in winter. So we gave them a very elaborate distribution. It had to be an overhead system. There was material handled that would be affected by the slighest draft and we worried about it so that we overdid the thing a little. We dropped in our usual outlet velocity of 750 to a neighborhood of 400. We had enough heating capacity in that building to heat it, although there was a limited air supply. The

building, however, did not heat in the winter; though it cooled very nicely in summer. There was plenty of heat there according to all calculations of heat. The trouble was evidently lack of forcible air diffusion. It stayed up overhead instead of being stirred up, as we stir up sugar in our coffee with a spoon. The easiest remedy was absolutely to block off half the outlets and thus increase the velocity. That being done, the temperature of the room under identical outside conditions rose just about 10 deg., that is, in the zone near the floor where we were interested. It was not a particularly high building.

This shows that in this instance the lack of efficiency was due not to design of outlets concerned, but to wrong velocity of distribution.

The same result could undoubtedly have been obtained by changing those outlets and bringing them down to the floor, but that was impractical on account of the manufacturing process. Higher velocities gave us the same effect by producing the necessary circulation of air.

As to radiators, I think there should be very great study (as given in Dr. Brabbée's laboratory—of the efficiency of location), but I think we should try as much as possible to separate efficiency of location from efficiency of the radiator itself. Undoubtedly there is a difference in efficiency of radiators, low radiators being more efficient than high ones. If we could take the same radiator and put it on the ceiling, the heating effect would be very small, that again is a question of location. We should, therefore, have some means of distinguishing between effectiveness of location and effectiveness of the radiator itself in producing a comfortable temperature where we want it. Undoubtedly radiators of larger radiation surface and smaller convection surface will produce greater comfort with a smaller surface. I don't think there is any question about that, inasmuch as 30 per cent of the heat is radiated and that travels in straight lines. On the other hand, increasing air circulation has a distributing effect which may be just as marked as the effect of radiation.

It is a very difficult and complicated problem. Personally, I don't know the solution.

PROF. F. B. ROWLEY: The problem of rating radiators seems to me to be rather complicated and one that has several variables. I think the danger is that we are too often considering the problem with only part of these variables under control; the others we are neglecting partially or altogether. Mr. Carrier brought out some of the points which I had in mind.

Now in Dr. Brabbée's work he has taken a radiator, which has a large amount of direct radiating surface, and has put it under the window where the heat from it will counteract the cold currents coming down from the window and across the floor. Under this condition one will get greater comfort than would be the case if the same radiator were placed at some other point in the room and the cold draft from the window allowed to pass over the floor.

There has been much discussion about the comparative merits of radiators which give off different proportions of their heat by convection and by radiation. In many cases comparisons have been made which have been unintentionally favorable to one or the other types. It is easy to understand that a radiator, giving off a large proportion of its heat by radiation may be placed under a window and keep the room temperature in a much more uniform condition than another

type of radiator placed in some other position in the room. On the other hand, the convection type might be so placed as to be given an advantage. Such experiments do not prove the superiority of either radiant or convected heat either in point of comfort or condensation. In other words, if each of the radiators were so placed as to give the same uniformity of temperature throughout the room and so as not to have any direct losses, I wonder if both the comfort and condensation would not be more nearly comparable. I think that many of the past troubles have been due to irregular temperatures about the room, and that comparisons have not been made under the same conditions.

I should like to ask Dr. Brabbée first how he arrived at 67 sq. ft. for the radiator which he used. Was it by actual surface measurements or by condensation? Second, was the drafting room in which he used the new type of radiator equipped and tested with the old type of radiation, and if so were 127 sq. ft. actually required?

E. A. MAY: I think there is one thing that we lose sight of in the arguments. Dr. Brabbée has brought out this particular point, that condensation alone should not be the exact measure of the heating efficiency of a radiator. I have here a pencil memorandum that was made prior to 1918 and this will answer Prof. Rowley's question, I think, because this was a radiator with 50 sq. ft. of radiation, the location was not changed, the temperature of the room was maintained at 70 deg., the pressure at the boiler was maintained at 2 lb. In one test a box was placed over the radiator and in another test it was bare. In the next test the bare radiator had an insulating board of asbestos placed behind it against the wall. Then the radiator was covered with a coat of aluminum and a test was made, the same temperature being kept. Then the insulated board was placed behind that. Then the radiator was given a coat of maroon Japan and tested without the insulating board, then with the insulating board. Bear in mind the temperature of the room was maintained on an average of 70 deg. in all the tests. The pressure at the radiator was sustained in all cases and it showed the following results:

I am going to give the heat emission in B.t.u. per hour. In box, 234; naked, 258; insulated, 249; aluminized, 214½; insulated behind the aluminized radiator, 207; maroon Japan, 250.5 and insulated behind the maroon Japan, 243; indicating that the radiator which had the aluminum coat and had the insulated board behind it emitted the least number of B.t.u., but the room was maintained at the same temperature. Therefore, it did it at the least expense for fuel. To my mind, then, it was the most effective from the heating point of view. That is, it was the most economical. While on the basis of total condensation the bare radiator showed the highest heat emission and would, if no other consideration were given—show the highest efficiency.

F. D. MENSING: The question was asked, what the effect would be of the same radiators in different locations. Elaborating on the statement made by Mr. Houghten that we have been testing rooms instead of radiators, I present below some figures on three sets of identical radiators. These radiators have been tested by Dr. Brabbée and Prof. Lockwood in different rooms. They are as follows:

	LOCKWOOD	BRABBÉE
Radiator	45 in. 2 col. 8 sec.	Same
Test room dimensions Lgth., Wdth., Hght.	12 ft. x 8 ft. x 7 ft. 5 in.	14 ft. x 9 ft. x 9 ft.
Date of test	Oct. 11, 1926	Sept. 17, 1927
Duration of test	2 hours	2 hours
Steam pressure	1 lb./sq. in.	1 lb./sq. in.
Steam temperature	216.5 deg. fahr.	216.2 deg. fahr.
Condensate temperature	214 deg. fahr.	215.3 deg. fahr.
Super heat	2 deg.	1.9 deg. fahr.
Room temperature	84.7 deg. 1 ft. from ceiling	80.7 deg. fahr. 1 ft. from ceiling
Room temperature	77.3 deg. 5 ft. from floor	70.9 deg. fahr. 5 ft. from floor
Room temperature	75.0 deg. 1 ft. from floor	1⅓ ft. from floor 61.4
Temp. surround room	73.6 deg. fahr.	33.9 deg.
Weight condensate 1 hour	9.50 lb.	9.43 lb.
Heat in steam corrected to B.t.u. per sq.ft. nominal surface	236	232
Radiator	22 in. 3 col. 14 sec.	Same
Test room dimensions	12 ft. x 8 ft. x 7 ft. 5 in.	14 ft. x 9 ft. x 9 ft.
Date of test	Oct. 20, 1926	Sept. 18, 1927
Duration of test	2 hours	2 hours
Steam pressure	1 lb./sq. in.	1 lb./sq. in.
Steam temperature	216 deg. fahr.	216 deg. fahr.
Condensate temperature	213.5 deg. fahr.	215 deg. fahr.
Super heat	2 deg. fahr.	1.7 deg. fahr.
Room temperature	86.4 deg. 1 ft. from ceiling	77.5 deg. 1 ft. from ceiling
Room temperature	76.9 deg. 5 ft. from floor	72.6 deg. 5 ft. from floor
Room temperature	74.5 deg. 1 ft. from floor	63.4 deg. 1⅓ ft. from floor
Temp. surrounding room	73.6 deg.	32.9 deg.
Weight condensate 1 hour	10.06 lb.	9 lb. 6¼ oz.
Heat in steam corrected to B.t.u. per sq.ft. nominal surface	238	234
Radiator	26 in. 4 col. 8 sec.	Same
Test room dimensions Lgth., Wdth., Hght.	12 ft. x 8 ft. x 7 ft. 5 in.	14 ft. x 9 ft. x 9 ft.
Date of test	Oct. 21, 1926	Sept. 17, 1927
Duration of test	2 hours	2 hours
Steam pressure	1 lb./sq. in.	1 lb./sq. in.
Steam temperature	216 deg. fahr.	216 deg. fahr.
Condensate temperature	213.5 deg. fahr.	215 deg. fahr.
Super heat	2.0 deg. fahr.	1.7 deg. fahr.
Room temperature	85.9 deg. 1 ft. from ceiling	83.9 deg. fahr. 1 ft. from ceiling
Room temperature	76.4 deg. 5 ft. from floor	75.2 deg. fahr. 5 ft. from floor
Room temperature	74.3 deg. 1 ft. from floor	65.2 deg. fahr. 1⅓ ft. from floor
Temp. surrounding room	73.3 deg. fahr.	34.1 deg.
Weight condensate 1 hour	10.01 lb.	9 lb. 8¾ oz.
Heat in steam corrected to B.t.u. per sq.ft. nominal surface	247	241

These figures require little explanation. You will note that there is only 4 to 6 deg. difference in B.t.u. transmission per sq. ft. of nominal surface in the two tests, while room temperatures vary as much in places as 13.6 deg.

My humble opinion is that you can get as many results as you design rooms, and that we have been testing rooms and not radiators.

H. M. HART: In order to save time I should like to discuss this question of radiator ratings.

I think we are trying to combine two separate and distinct problems which should be dealt with individually.

First, I think we should arrive at some uniform methods of rating a radiator. The heating engineers are very much in need of this so that they can properly lay out their work and also make comparisons between radiators of different manufacturers.

The question of the proper location of radiators for obtaining the most efficient results is an entirely different problem, on which further research is necessary.

On the question of the location of this radiator, it was mentioned by Dr. Brabbée that the custom in France was to depend on radiated heat almost entirely. Our experience has been in large offices that the radiant heat from a direct radiator in a room is very objectionable. In a large office which is being occupied by a number of people, those who are near the radiator are made very uncomfortable by the radiant heat if the people at distant points are to be kept comfortable. In Chicago they are considering writing into the ordinance that every radiator shall have a shield on it to cut off that radiant heat.

MALCOLM C. W. TOMLINSON: I just want to mention one little thing in connection with adjacent heat from radiators. Most of you folks are interested in the radiator that works at low pressures. Some of us, however, are interested in the type of radiator that works at higher pressures than we will say 5 lb. In manufacturing processes you often have to have higher pressures because of the temperatures that you desire to obtain. By varying in a vacuum dryer the type of surface behind the pipe coils, it is possible to maintain the same temperature with various pressures. I can obtain the same result, in striving to maintain 270 deg. fahr., for instance at 30 lb. pressure or at 45 lb. pressure, just by varying the type of surface behind pipe coils that are adjacent to the round or cylindrical surface of the dryer.

L. A. HARDING: My remarks refer to Dr. Brabbée's statement in reference to the direct radiation installation in the laboratory drawing room where he stated a saving of about 46 per cent was made in the amount of direct radiation. This does not appear in the paper printed in THE JOURNAL. If I understand Dr. Brabbée correctly the saving of 46 per cent in direct cast-iron radiation was based on an estimated heat loss of this room.

He does not state this estimated loss. A 46 per cent saving does not appear reasonable, however, if the heat loss estimate calculations were made in accordance with the present-day heat transmission factors that such a large saving would be possible no matter what type of direct cast-iron radiators were employed or their location in the room.

If I understand correctly the saving in radiation is attributed to a type of radiator which tends to prevent high temperatures existing at the ceiling. If the heat loss through the ceiling of this room was entirely neglected, it would probably not account for the assumed saving in radiation.

DR. BRABBÉE: It is quite a difficult thing to answer so many questions; especially if one doesn't understand and talk English well; however, I will try to answer as completely as possible.

Professor Lockwood said that we should not compare single rooms, but houses. First, I think, we should concentrate on one room for the following reasons: We often have practical cases where we do not want much heat above the room, for instance, in the bedrooms of the average home. Then in many apartment houses some floors are unrented and are wastefully heated by high temperature at the ceilings. Further: In each room there develops an air circulation, and as soon as the room is overheated on the ceiling, the hot air passes out through the leakage of the windows and heat is wasted. You finally have heard throughout the entire discussion that not only should the radiator be studied, but the room itself. We

therefore would complicate our problem tremendously if we went right ahead to buildings instead of studying first the conditions in single rooms. From all these considerations, I think, that if we have first solved the problem of a single room, then it will be easy enough to answer the question about the whole building.

Mr. Houghten has referred to the fact that we have to be careful not to mix up the testing of radiators and the testing of rooms, and that results in one room could just be reversed in another room. But we make our tests on a comparative basis; we test different radiators in the same room and the room, therefore, does not play any important part in the test. The test results are relative and it is just one of the great advantages of this method that the relative values of the objects tested will be unchanged in wide limits.

These investigations were started 15 years ago when we tested stoves in small rooms in a cellar. Then we put these stoves into other rooms on higher floors, and the relative results have been the same. We went into great detail with these practical tests just to show that the results obtained in the small rooms were correct—certainly not in the second decimal point, but in a practical way; and this, I think, is a most important fact.

Mr. Bolsinger asked if there was not a great difference in placing radiators beneath the windows or otherwise. I have given two examples. In one, the radiator was on the rear wall and the other radiator on the window front. But we noted that such a test is not fair, because the location of the radiators was so different, and therefore we placed in the second example, both radiators underneath the window in a different room, very much larger, and in Buffalo instead of New York, and yet the result was substantially the same. It is certain that if we concentrate the heat output more in the lower portions of the room and avoid overheated ceilings, we can use milder heat, less surface and less fuel, and that accounts for the facts Mr. Bolsinger mentioned.

From France comes a very interesting note. They tested steam and water radiators under different conditions. They found that by lowering the water temperature more comfort was obtained from the same radiators, because lower temperatures create longer heat waves which secure more comfort than short ones.

Mr. Carrier mentioned factories, but I think I have said that our investigations up to date are made for human housing purposes; I mean for dwellings, apartment houses, hospitals, schools, etc., but not factories. I think I have also explained that all our investigations were made with gravity forces and not with forced air circulation.

Professor Rowley asked how the radiators were figured. In both cases it was actual heating surface. We could not make tests if the originally installed 120 sq. ft. of radiation was too much, but we can show curves in which the temperature difference between outside and inside was taken for both cases, and in studying the curves there is not the slightest doubt that with the smaller heating surfaces, higher comfort conditions have actually been established.

Mr. Mensing has shown tables indicating that with the same radiators, very much different temperatures in different rooms were obtained. That is just one more reason why we should not try to measure in an absolute, but in a relative way, just as we did. The very great advantage of the method outlined is that

by testing comparatively in equal rooms, we are practically independent of the arrangements of the rooms.

Mr. Harding said that direct heat may be very uncomfortable. I have shown a drafting room in which the draftsmen sit very close to the radiators, and one of my special points was to go into this room every day and ask if anybody was annoyed by direct radiation. But the men always said they felt very comfortable—much more comfortable than in the room they had previously used where this kind of radiation was not installed.

It might be well to stress one point a little more. If we crowd too much radiation into one space, then it can become somewhat uncomfortable. The best way to install radiators is to distribute them everywhere where surfaces of high cooling effect are located, and in this case we will not be annoyed by too much radiation.

Mr. Tomlinson said that by varying the form of the surfaces of different heaters, he could get better results with lower pressure, which means that by changing the character of the surfaces of the heaters, different results will be obtainable.

And here comes the *neck-high efficiency*. I only hope that the distinguished gentleman who put up this question will never be uncomfortable or sick, because then he would very much like to have his feet warm, but not his neck.

Practice very often goes ahead of science and America is well known for that fact. If you read the *New York Times* of last Sunday, Mr. Parker of England said: "English people wake up! The Americans are far ahead of you. They may not have the scientific investigations which we have, but they *do* the things, and if you don't wake up, you will be very much behind."

Practice has often solved problems where theory could not follow as quickly, and many inventions have been made which were not understandable at that time to pure science, but nevertheless those inventions have been made and practical results have been obtained. I have shown you three examples taken out of hundreds that it is actually possible to obtain higher comfort with less heating surface, with less condensation, and therefore with less expense.

No 789

PROPOSED METHODS FOR TESTING RADIATORS

By F. C. Houghten,[1] and S. R. Lewis[2]

MEMBERS

Introduction

THE term radiator or heater as used in this discussion is meant to include any device located in, or immediately adjoining a room or space to be heated, which transfers heat from any heat carrying medium other than air, or transforms some other form of energy into heat, and then transfers it, to the air or objects within such room.

Thus defined the term radiator or heater will include the various types of direct radiators, enclosed radiators, cabinet heaters, unit heaters, flue heaters and semi-indirect radiators located in a surrounding wall or floor of the heated space, using either hot water, steam or any other heat carrying medium other than air brought from a distance to replace the air within a room. It will also include electrical heaters of any of the above forms and of stoves or open fires. It will not include warm air furnace, or indirect heating, where air is conditioned some distance away from, and then brought to the room to replace the air within the heated space.

Function of a Radiator

The function of a radiator or heater as defined is to supply heat for keeping occupants comfortably warm or for maintaining the air or objects in the heated space at some desired temperatures.

A measure of the radiator's capacity to fulfill its function depends upon the purpose for which the heat is supplied. If it is to make occupants comfortably warm, then its true capacity to fulfill its function will obviously be a measure of the size of the occupied space, or of the number of occupants made comfortable under some specified surrounding conditions. If its purpose is to maintain a given space at a desired temperature, then the volume of the space conditioned under some specified surrounding condition will be a measure of its capacity to fulfill that function.

Rating of a Radiator

The capacity of a radiator to fulfill its true function as mentioned before is very

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difficult to define so as to meet the varied requirements of heating practice. In the past, radiators were rated upon their actual external surface. More recently ratings have been based upon actual heat output in B.t.u. per hour or in units of equivalent square feet of radiation equal to 240 B.t.u. per hour.

Ratings based upon area of surface are of little or no value to the heating engineer when applied to the various types of radiators on the market. Work of R. V. Frost, C. W. Brabbée, Thornton Lewis and others, has shown conclusively that ratings based upon heat output are not always a true measure of the capacity of a heating unit to fulfill its true function.

Brabbée shows that under certain conditions one radiator heated a room to a comfortable temperature when using 7.9 lb. of steam per hour, whereas another radiator required 16.3 lb. of steam to give like conditions of comfort in the same room. It would seem the part of folly to rate the second radiator more than twice as high just because it took that much more energy to fulfill the same function. It would seem from the single test cited that both should be given the same rating. There is, however, insufficient evidence available at this time to warrant such a radical step and such must await the results of extended investigation. It has not been proven that the first radiators mentioned will show the same relative capacity to fulfill its function in different types of rooms. It is quite possible that under different conditions of heating as regards size and shape of room, window area and air change, the results may differ widely or even be reversed; that is, the second radiator may be the more economical in some other type of room.

Work of C. W. Brabbée indicates that most satisfactory results are to be had with a radiator emitting a larger percentage of its heat as direct radiation, while the work of R. V. Frost indicates that a radiator emitting most of its heat by convection is most effective. Again Thornton Lewis shows that the place, direction and velocity of heated air leaving a unit heater has a marked effect on its ability to fulfill its function of making occupants comfortable with minimum expenditure of energy.

Need of Research

These facts all indicate the great possibility of research in this field. At the same time the variation in the results indicate that sufficient information is not at hand to finally rate heaters on the basis of their ability to fulfill their real function.

The needs of the profession and industry require study along two lines: *First*, research directed toward the establishment of more complete knowledge concerning a radiator's ability to fulfill its function of economically maintaining a comfortable condition in occupied space; *Second*, research aiming toward correction of the chaotic condition which now prevails in the matter of rating radiators.

Logically, perhaps, attack of the second problem awaits solution of the first. The magnitude of the first problem and the length of time required for its solution makes it desirable, however, to attack the second at once, even though only partial relief is promised.

This means that we must proceed with standardizing rating methods on the basis of heat given off by the radiator rather than on the basis of its ability to fulfill its true function, pending further study of the latter. This was the feeling of the Technical Advisory Committee when it submitted to the Society the code which was

adopted at the last Annual Meeting. The Committee, with some change in personnel was continued and now has under consideration the desirability of revision of this code.

Inter-relation of Radiator, Room and Occupant

In testing radiators for the purpose of giving them a rating on the basis of heat output, the selection of the test room is the most important part of the work. The function of the room is to simulate as nearly as possible the average environment of a radiator, as used in practice. The room must not be too complicated or costly to build, and it must be easily duplicated. The size, shape, construction and exposure of the room as well as the window area, location of the radiator and position at which temperatures are to be taken, are of greater or less importance and must be specified at least until it is proved to what extent they influence results.

Since the purpose of the test room is to simulate the usual environment of the radiator, it is well to consider the function of a room as well as that of a radiator in ordinary heating practice.

The function of a radiator in heating is to supply heat for making occupants comfortably warm or for maintaining other objects or materials or the contained air at some desired temperature. The function of the room enclosure, in so far as it provides shelter from the cold is to minimize and control heat loss from the space.

Consider the thermal exchanges taking place in an occupied room, heated by a direct radiator, and the effect of the room enclosure on the radiator. Consider the room as having one window under which the radiator is placed.

Heat leaves the radiator by two distinct and well-known physical phenomena; by radiation and convection.

Radiation

Radiant energy emanates in straight lines from the radiator in all directions. That which is intercepted by an occupant warms him as do rays from the sun. Other objects intercepting these radiations are likewise warmed. If the radiant energy is intercepted by the enclosing walls of a room, they are absorbed, and the energy transformed into heat, some of which passes through by conduction and is lost to the outside. Some of the heat which was transformed from radiant energy at the surface of the wall is given up to the air in the room, thereby becoming convected heat, while another portion is emitted into the enclosed space as direct radiation to be reflected or transformed and absorbed when it is intercepted by other objects. The heat interchange between the radiator and the wall is in accordance with Steffens and Boltzman's law. The radiator emits heat at a rate depending upon the fourth power of its absolute temperature and other factors including the character of its surface. The wall either reflects or absorbs that which it intercepts. The wall radiates heat at a rate depending upon the fourth power of its absolute temperature and other factors, including its projected area, the condition of its surface, and the radiator reflects or absorbs that which it intercepts. The resultant exchange between the heater and wall depends upon the difference between the fourth power of the absolute temperature of the radiator and the fourth power of the absolute temperature of the wall.

If no walls were present the radiation emitted by the radiator would be inter-

cepted and absorbed by more distant objects, in which case the heat loss in this direction would depend upon the difference between the fourth power of the absolute temperature of the radiator and such objects. If the radiant energy is not intercepted but is directed out into inter-stellar space, the heat loss through this solid angle will be maximum since the radiator will receive no heat in return.

In so far as radiant energy from the radiator is concerned, the walls intercept and partially return such energy as heat to the air and objects in the heated space. At the same time the walls reduce the heat loss from occupants and objects in the heated space by radiation. The loss here again depends upon the difference between the fourth power of the absolute temperature of the objects in the space and of the walls, or more distant objects or space receiving radiation from the former.

Convection

Air warmed by, and carrying heat from the radiator by convection is confined to the heated space by the enclosure. The air thus confined to the room soon becomes heated to the more or less even temperature desired and therefore reduces heat loss from the occupant and objects by convection. Heat loss from the radiator by convection is decreased as the temperature of the air approaching it rises.

The window area differs from the rest of the enclosure in its relation to the radiator, occupant and air in the room in several respects. Radiant energy from the occupant and radiator is only partially absorbed. In so far as the glass is transparent, radiant energy passes through as though the glass were not there. Therefore, heat loss by radiation from the radiator, occupants or other objects, is increased. Heat transmission is much greater through glass than through most other types of wall construction, while air leaks through cracks in and around windows. The greater heat loss and air leakage through the window tends to set up different convection currents in the room than would exist were the window replaced by other construction.

In summing up the inter-relation of the occupant and the radiator and wall, the last two have the following effects:

1. By emission of radiant energy the radiator warms the occupant directly.
2. By emission of radiant energy the radiator warms the enclosing walls.
3. The radiator warms air by convection which, if it comes in contact with the occupant, imparts heat to him or rather decreases his heat loss to the air.
4. The enclosing walls confine the convection currents of warm air set up by the radiator and tends to bring about uniform temperature of the air within the heated space.
5. The enclosing walls of the room reduce the heat loss from the occupant by radiation.
6. The enclosing walls reduce the heat loss from the radiator by radiation, and by giving part of that which it intercepts back to objects and air in the room, makes it available for warming the occupant.

Test Methods

An ideal radiator testing room would be one in which all the inter-related reactions between radiator, room and occupant take place normally. It is, however, very difficult to so design a single test room that it will meet all these requirements.

In testing radiators for rating them on the basis of heat output, there are two objects which must be given primary consideration: *First* and most important, the test must demonstrate, and the rating must reflect, the relative capacity of different heaters for emitting heat under some accepted conditions. This is particularly needed because of the great diversity of types and designs of radiation which are now tested under widely different conditions; *second*, the rating should reflect as nearly as possible what the radiator will do in an actual installation.

A number of methods of test have been suggested all of which aim to fulfill

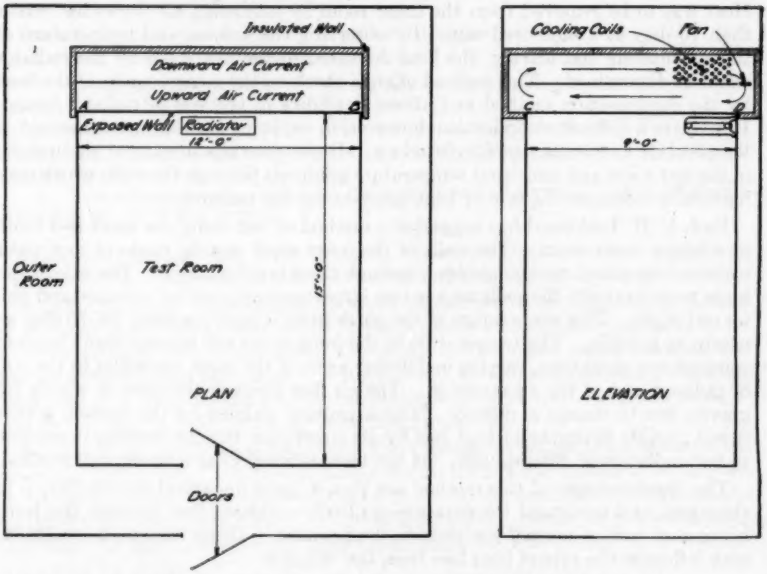

FIG. 1. PROPOSED TEST ROOM WITH ONE EXPOSURE

the requirements as previously outlined. Each method has certain advantages but none seem to satisfactorily meet all requirements.

Brabbée[1] developed a method of test by which two inner test rooms of like dimensions and construction are located in a larger room. The outer room can be cooled by refrigeration. The walls of the inner rooms are designed with the idea of having the same heat transmission with a temperature of 70 deg. inside and 32 deg. outside as would result with ordinary construction with 70 deg. inside and zero outside. All radiators are tested with the same temperatures in the inner and outer rooms making it possible to test only one size of radiator of any design. The

[1] The Heating Effect of Radiators—A Practical Method for Testing Radiators by Comparison—by Dr. C. W. Brabbée, N. Y., published in JOURNAL A.S.H.&V.E., Nov., 1925 and 1926.

two inner rooms make it possible to compare the performance of two radiators directly. One advantage claimed for the method is that it simulates the most severe conditions usually met, namely, zero weather. It is referred to as a cold wall method. The outstanding disadvantages of the method are: *First*, difficulty and expense of cooling by refrigeration; *second*, it is limited to testing a radiator of only one size of any design if the advantage of zero outside equivalent is maintained.

R. V. Frost[4] proposed a method of test consisting of an inner test room with insulated walls to be kept at 70 deg. surrounded by an outer room also at 70 deg. Heat was to be removed from the inner room by admitting air somewhat cooler than 70 deg. at a measured rate. By observing the volume and temperature of the air entering and leaving, the heat delivered to the test room by the radiator could be determined. This method offers a check on the measurement of the heat by the condensation method and allows flexibility in the size of radiator tested. It involves a difficult complication, however, in requiring accurate measurement of temperature and volume of circulated air. It also provides unnatural air currents in the test room and unnatural temperature gradients through the walls which may materially influence the rate of heat emission by the radiator.

Prof. E. H. Lockwood has suggested a method of test using one inner test room in a larger outer room. The walls of the inner room can be made of any tight construction since heat transmission through them is not a factor. The side of the inner room opposite the radiator has two large openings, one for entrance and one for exit of air. The temperature of the outer room is kept constant, 68–70 deg. as nearly as possible. The temperature of the inner room will automatically become constant in a short time, varying in different parts of the room according to the size of radiator and of the air openings. The air flow through the room is wholly by gravity due to change in density. The advantage claimed for the method is that it will provide flexibility of heat loss by air circulation thereby making it possible to test radiators of different size. It has been referred to as a warm wall method.

The disadvantages of this method are that it gives unnatural air circulation in the room, and unnatural temperature gradients and heat flow through the walls because of lack of normal low outside temperature. These unnatural conditions may influence the rate of heat loss from the radiator.

The Technical Advisory Committee on Radiation in its code for testing radiators for rating purposes, which was adopted by the Society last January, specified a test room consisting of one chamber within another. The inner room is to be built of any comparatively air tight construction having low resistance to heat loss by transmission. It is to be maintained at 70 deg. at the breathing line in the center of the room. The temperature of the outer room is to be varied so that the transmission through the wall from the inner to the outer room will take care of the heat emitted by the radiator in 70 deg. air.

The advantages claimed for this method are flexibility in the size of radiator which can be tested, without unnatural air currents, and with approximately the same mode of heat loss from the room as takes place in practice. Its disadvantages are

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[4] Proposed Code for Rating and Testing Radiators—by R. V. Frost, JOURNAL A.S.H.&V.E., Dec., 1925.

lack of normal temperature gradients through the wall and lack of normal low temperature outside.

Another suggestion for the design of a test room is, that flexibility of size of radiators which can be tested can be had by installing a heat absorber in the form of cooling coils on the inside walls of the inner room. This would add flexibility to the advantages of the Brabbée method, without the excessive air circulation. It would inject the disadvantage of unusual temperature of surfaces in view of the radiator and would set up unusual convection circuits in the room.

Characteristics of an Ideal Test Room

From analysis of the three methods given, it appears evident that an ideal test room should have the following characteristics:

1. It should make possible the testing of radiators varying in size up to at least 40 and possibly 75 equivalent square feet.
2. It should not be subject to excessive or unnatural air currents.
3. Heat loss from the room should be natural, that is, largely by transmission through the walls.
4. Temperature gradients through the walls should be normal. That is, it should preferably be a cold wall method.

The reason for the first three desirable characteristics mentioned is obvious. The effect of the cold wall method on results may bear further analysis.

A cold outer room results generally in a lower temperature of the inside surface of the wall of the inner room which in turn increases heat loss from the radiator to this surface by direct radiation. The cooler inside surface also stimulates convection currents within the room. A radiator will, therefore, receive a higher rating from tests in a room having a lower temperature of inside wall surface because of greater loss due to both direct radiation and convection.

A lower outer room temperature will also increase exchange of air between the inner and outer rooms. However, unless the air change due to this cause is great enough to lower the temperature of the air in the inner room, its only effect on the radiator will be that caused by increased circulation. Hence with a reasonably tight wall the effect of increased infiltration due to a lowered outer room temperature may be ignored.

The inside surface temperature of a wall depends upon the thermal transmission constant for the wall as well as upon the temperature of the outside air. With 70 deg. air in the inner room and zero air in the outer, an 18-in. brick wall with furring, lath and plaster will transmit 9.8 B.t.u. per sq. ft. per hr. and will give an inside surface temperature of 59.5 deg. Thirteen-inch, 9-in. and 4-in. brick walls of the same type will transmit 11.9, 14.0 and 17.5 B.t.u. per sq. ft. per hr. and will give inside surface temperatures of 57.2, 54.9 and 51.2 deg., respectively. If the 9-in. wall and zero outside is accepted as satisfactory for the radiator test, then it would be just as well to choose the 4-in. wall with a 14 deg. outer room temperature which would give the same heat flow of 14 B.t.u. per sq. ft. per hr., and the same inside surface temperature of 54.9 deg. Likewise a $^1/_2$-in. plaster wall on metal lath would give the same heat flow per unit area of wall, and the same inside surface temperature—which is the only factor affecting the radiator—with an outer room temperature of 39.9 deg. A sheet metal wall would allow a much smaller tempera-

ture difference between the inner and outer rooms with the same inside wall temperature of 54.9 deg. If the inside surface of the sheet metal were painted, this condition would probably be obtained with a greater rate of heat flow, since the surface transmission constant for a painted surface is probably higher than that for a plaster surface.

The figures given are obtained by computation from values given in THE GUIDE. The total transmission per square feet per hour for any wall being obtained by multiplying the transmission constant from Table 6, of THE GUIDE 1926–7 by the temperature difference. The difference between the inside air and inside surface temperature was found by dividing the total heat flow in B.t.u. per hour by the surface coefficient.

It should be pointed out that the inside surface temperature, the outside air temperature and heat flow will have the values indicated above for any given room only with a radiator of one size for any type, and that if one could decide that any set of conditions as regards outside air temperature and inside surface temperature were ideal that ideal would only be realized in testing a radiator of one particular size. It, therefore, follows that if the test room is to accommodate radiators of a wide range of heat output then any accepted ideal of wall temperature can only be approximated.

It also follows that if it were possible to decide upon any desired outside temperature as ideal and any wall construction as typical, the resulting inside surface temperature which is the only factor affecting the radiator can be had with some other wall construction giving the same total transmission with a lower outside temperature. This holds rigidly true for all the wall area except that portion near the radiator which is heated by it to a higher temperature and for the window area.

It was pointed out previously that ideal cold wall conditions could be had only for one size of radiator in any given room. It is interesting to see what size room of a certain type of construction will accommodate radiators of different sizes.

If the ideal of outside temperature and construction mentioned above (namely, the equivalent of 9-in. brick with furring, lath and plaster with 70 deg. inside and zero outside) is accepted, then Columns 5 and 6, Table 1, give dimensions of a room built of 9-in. brick with furring, lath and plaster which will lose heat by transmission through all four side walls at the rate per hour indicated in Column 1. Columns 2, 3 and 4 give the least number of sections of column radiation and the kind of sections necessary to emit heat at approximately this rate. Columns 7, 8 and 9 give, respectively, the temperature difference between the inner and outer room, the outer room temperature and the inside surface temperature of the wall of the inner room for the different rates of heat outputs in a 12 x 15 ft. room of the same kind of construction. The table indicates very clearly that a room designed for testing a wide range of radiators can only give appreciable advantage of cold wall conditions for a small part of this range.

A Practical Test Room

In view of previous statement and because there is greater need for a rating which will reflect the relative capacity of different radiators to emit heat than there is for a rating which will reflect accurately the true capacity of the radiator for heat-

ing under certain definite conditions, it would seem wise to waive ideal cold wall conditions for greater flexibility and simplicity.

In the discussion so far only an inner room cooled on all four sides has been considered. Such a condition is unusual in practice. A room exposed only on one side with the radiator near this wall is most usual. It is probable that convection currents and heat emission by direct radiation differ widely in rooms having one or more exposures. In fact it is quite possible that the number of exposures has a greater effect on the heat output of a radiator than the outside temperature. It would seem desirable, if possible, to have the test room exposed only on one side.

Provided sufficient cooling can be had through the smaller area of one wall, it would be more convenient and would probably make the testing equipment less expensive. If artificial cooling is resorted to, and under any conditions it will be highly desirable that it should, it can probably be more easily applied to the one side of the room. Fig. 1 illustrates what would seem to be a convenient and effective test arrangement, which would as nearly approximate actual conditions, as is possible with flexibility.

The outer room would be kept at 70 deg., thereby approximating a room with one exposure, that is a room in a building with adjoining space heated. The construction of the inner room walls with the exception of the exposed wall AB would not matter so long as it was substantially air tight. The construction of the exposed wall would depend upon the rate of heat transmission desired and temperatures available. It must be substantially air tight. It could well be built of sheet metal, thereby allowing maximum heat transfer with minimum temperature difference. Painted sheet metal should give no different surface effect than any other painted wall. If greater resistance to heat flow is ever desired, this could be accomplished by adding some such material as wall board or celotex to the sheet metal surface on either the inside or outside. It must, however, be applied with uniform contact and form a smooth even surface. Considerable flexibility in heat loss from the exposed surface could be had in this way or by blanking off part of the exposed wall with cork board.

A window may or may not be contained in the wall exposed as is desired. The window would only partially represent actual conditions in that it would not permit direct radiation to a low temperature. While no room is found without at least one window, there are perhaps as many rooms with more than one window as there are with only one, and it is not universal practice to place a radiator under the window. These facts, together with the added complication which a window makes without any considerable advantage, would suggest leaving the window out of any test room built.

Suggested Method of Attack

There are a number of questions in connection with rating of radiators and method of test for that purpose which are not answered by the published information available. It is hoped that this discussion will aid in their solution by bringing out many facts which are no doubt to be had from work already done by the several interested laboratories. It would seem that the Laboratory would serve the Society, Profession and Industry best by building an experimental test room

and by endeavoring to find a solution to these questions which cannot be otherwise disposed of. Among such questions are the following:

1. Should a new unit of heat output be used in rating radiators to replace the equivalent square foot defined as 240 B.t.u. per hr. which has a double and confusing meaning? A new unit to be called a Kent has been suggested. If adopted, a Kent will be defined as some definite rate of heat output in calories or B.t.u. per hour. If adopted this new unit should represent some whole number of heat units which can be easily divided into the estimated heat loss from the building or room to be heated as for example: a Kent may be defined as 250, 500 or 1000 B.t.u. per hr. and units of radiation will then be rated as so many Kents per section or unit.
2. Is condensation the best measure of rate of heat output from the radiator?
3. What should be the size of the room?

TABLE 1. SIZE OF ROOM NECESSARY FOR DIFFERENT RATES OF HEAT LOSS WITH 70 DEG. TEMPERATURE DIFFERENCE. ALSO TEMPERATURES NECESSARY FOR SAME HEAT LOSS FROM 4 WALLS OF 12 x 15 x 9 FT. ROOM WITH 70 DEG. INSIDE AIR. 9 IN. BRICK WALL WITH FURRING, LATH AND PLASTER

Heat Output	Type of Radiator Approximately Giving Heat Output,			Dimensions of Room Giving Heat Loss from 4 Sides for 70° Inside and 0° Outside,		Temperatures for Heat Loss from 4 Sides of 12 x 15 x 9 ft. Room with 70° Inside,		
	No. sections	Columns	Height	Area of wall	Dimensions of room	Temp. drop air to air	Outside temp.	Inside surface temp.
600	1	1	20	42.9	1 x 1.4	6.2	63.8	68.7
1000	1	2	23	71.4	1 x 3.0	10.3	59.7	67.8
2000	1	4	32	142.9	3 x 5.0	21.2	48.8	65.6
3000	1	4	45	214.3	5 x 6.9	30.9	39.1	63.4
4000	2	4	38	285.8	7 x 9.9	41.2	28.8	61.1
5000	2	4	45	357.2	9 x 10.9	51.5	18.5	58.9
6000	3	4	38	428.5	11 x 12.8	61.8	8.2	56.7
7000	3	4	45	500.0	12 x 15.8	72.0	− 2.0	54.5
8000	4	4	45	571.5	15 x 16.8	82.4	−12.4	52.3
10000	5	4	45	714.5	18 x 21.7	102.9	−32.9	47.9
12000	6	4	45	857.5	22 x 25.6	123.5	−53.5	43.4

4. At what point in the test room should the temperature of 70 deg. be maintained as representing that of the room?
5. What difference in heat output will a radiator show depending upon the temperature of the outer room or upon the temperature of the inner surface of the inner room?
6. Is it feasible to test radiators in a room with only one exposure, and how much will the heat output of a radiator tested in such a room differ from that shown for the same radiator tested in a room with four exposures?
7. Is the rate of heat loss from the radiator materially affected by removal of heat from the test room by transmission through the walls rather than by air change?
8. What correction should be applied to the heat output from a radiator when tested in a room at a temperature other than 70 deg?
9. How best can the temperature of the outer room be maintained?

DISCUSSION

KONRAD MEIER (WRITTEN): For a number of years the writer has been advocating research on radiation, particularly in reference to the proper application of the heat within the room, which had remained a neglected phase of the art. In the August number of THE JOURNAL the Advisory Committee on Radiation

has asked for criticism and suggestions regarding the proposed tests. The paper on the method of testing by Messrs. Houghten and Lewis, published in December, now gives the opportunity to present this in the form of discussion, reference being made to the set of questions raised.

1. There seems to be no valid reason for a new method or unit of rating. The heat output or the emission, like the heat losses, can always be expressed in B.t.u. or an equivalent, although there is little excuse for the latter. The room heating efficiency to be tested in particular is not dependent on the radiator alone. If only for that reason, it could not be stated in reference to it with any degree of fairness. It is a relative value to be expressed by itself as the ratio between the theoretical heat requirement of the room and the actual heat that must be expended for attaining the desired temperature in the occupied zone. In a sense it is a criterion of quality in heating, defined by the delivery of the heat at the proper time and place and resulting from design, manner of application and location relative to the exposure.

2. The condensation method is probably the most reliable one for determining the heat output and is easily applied to the present purposes.

3. The size of the test room would seem to be immaterial, if presenting no unusual conditions, particularly as to height. It would be interesting, however, to test with different heights of ceiling, which might be practicable to obtain.

4. For the purpose of this investigation temperature readings should be taken at different levels and parts of the room, which would show the distribution and delivery of the heat. In doing this, the time should be noted within which comfort is attained. And for these tests it seems proper to deviate from the usual standard of 70 deg. fahr. at 5 ft. from the floor and adopt the more expressive one for knee height, in which case a lower temperature will be found acceptable.

5. The heat output may not be materially affected by cold inside wall surfaces, but these would certainly result in a different distribution of temperature or room heating effect. Moreover, the time for reheating, as well as the factor of heat absorption would be abnormal.

6. It is not only feasible to test radiators in rooms with only one exposure, but proper to do so if we are to determine the most efficient way of taking care of the transmission and infiltration as leading to uniform temperature in all parts of the room. According to the distribution, the heat expended will deviate from the calculated amount. The latter being easily checked, we shall be able to establish the room heating efficiency for a clear-cut and most frequently occurring situation. Sufficiently accurate conclusions can be drawn from this for rooms with more than one side exposed. In fact, absolutely accurate figures would be of doubtful value in view of the great diversity of conditions met in practice. For similar reasons little would be gained by knowing the effect on the output of one radiator for four exposed sides, in as much as this unit would have to be larger than good practice would demand, unless it should be shown that there is no advantage in placing the heating surfaces with a view to neutralizing the effects of exposure.

The test room should be suited not only for determining the output. It should at the same time permit observation of the room heating efficiency for identical conditions and equipment. Thus only the kind of radiation, its manner of application, exposed or screened, and the location would be varied as required for com-

parison. If provided in that sense, the one-sided test room proposed by the authors would seem to answer all purposes, since it will be easy enough to maintain the other three sides at desired temperatures and, for further investigations, to effect some cooling of the floor, the ceiling or the corridor wall by suitable controlled connection with the cooling arrangement.

7. The output of the radiator is likely to be affected by the removal of the heat through air alone, since that method would result in air movements entirely different from those created naturally and such air currents would also make a difference in regard to the distribution of the heat, which is under investigation.

8. If the test room is kept within a few degrees of the normal temperature, no correction would be necessary outside of that due to temperature difference between the room and the heat carrier. However, for the purpose of determining the room heating efficiency such excess temperature should be avoided. It seems practicable to do this, if the unit to be tested is of stated capacity equal to the heat loss of the room and made up so that sections can be added or omitted in case of unexpected material discrepancies.

9. The arrangement of cooling coils suggested in the paper should serve very well, if used in connection with a wall and window of ordinary construction and known thermal properties. A sheet metal partition as shown would not represent normal conditions, as desired for instance, when testing radiators under windows where the heating surface is placed on a solid wall, but below the principal cooling surfaces. This wall should be not less than 16 in. and the sill of usual height and design. Again, a fair-sized window would give the desired opportunity to quick variation of test conditions within certain limits without disturbing other factors.

It seems entirely feasible to run these tests not merely to complete and confirm our data on heat emission or the output of radiation, but at the same time to clear certain points regarding the application of the heat as affecting the room heating efficiency. They should include the different types of exposed surfaces, as well as the screened, the modern invisible and other indirect devices, but each in the location for which it is intended. Indeed, not many patterns are equally well suited for inside walls and under windows. To obtain comparative data for these universal ones in different locations will be interesting, though less important than the findings in regard to the kind of radiation, the manner of application and the location that will give the highest room heating efficiency and will require the least output for reheating and for maintaining greatest comfort in general. This information is not essential for calculating the amount of heating surface to be installed and probably there will be no need of revising our figures in that respect, except that allowances might suggest themselves for unfavorable location. If poor room heating efficiency has not received more attention heretofore, it is because it can usually be made up by greater intensity and duration of service, that is, by giving more steam. Nevertheless, it will be worth while to save the extra steam thus uselessly expended, in as much as conditions in other respects can be improved by selecting and applying radiation with a view to efficiency rather than the usual commercial considerations. It will also be most timely to know the facts regarding the various devices that have come up of late to satisfy the aesthetic sense. Possibly it will lead to other solutions, that would be acceptable from all points of view, including the hygienic, which is too often lost sight of, but undoubtedly deserves more attention.

E. H. LOCKWOOD (WRITTEN): The design of a radiator test room is an important topic, since upon it will depend largely the cost of the equipment. Some types of test rooms may require an initial outlay of several thousand dollars for insulating material and refrigerating machinery, followed later by rather heavy operating expenses. It is proper to inquire whether the costly apparatus has advantages which will justify its use.

Radiator test rooms may be divided, for purposes of discussion, into three general classes whose characteristics may be described roughly as follows:

Class A. An existing room of moderate size with one or more walls having outside exposure, which can be devoted temporarily or permanently to radiator testing. Present handbook data for heat output from radiators have been obtained almost exclusively from rooms of this class. By using care, under favorable weather conditions, reasonably satisfactory results can be had from this type of room. Its drawbacks arise from uncontrolled variations in outside temperature, direction and velocity of the wind, sunlight and variations in size and exposure of each test room.

Class B. A room of specified size and construction, wholly or partly surrounded by an artificially cooled room, the latter having heavily insulated walls to prevent heat loss. The advantage of this arrangement is the uniformity of temperature that can be maintained in the test room at all seasons of the year. Its chief disadvantage is the initial cost and operating expense, which in most cases will render the equipment prohibitive. A further drawback is inability to handle conveniently radiators of different heat output. The equipment is slow and cumbersome, since the refrigerating machine must run many hours to reach the steady temperatures required for beginning a test. Few test rooms of the *Class B* type have been built. An excellent example will be found at the Brabbée Laboratory of the American Radiator Co., which was completely described in THE JOURNAL, November, 1925.

Class C. A room of specified size and construction, surrounded by a larger room maintained at approximately 70 deg. fahr. The test room in this case can be made of inexpensive material, such as composition board, and can be located in some convenient part of a shop or laboratory where a fairly constant indoor temperature is maintained. The novel feature of this type of room is the use of openings in the walls remote from the radiator, by which hot air can escape from the test room by gravity circulation, with replacement by continuous inflow from the surrounding room.

An experimental test room of this type has been in use at Yale University for the past two years, where it has been found to possess the good features of the other types, simplicity of operation and consistency of results. A photo of this room is shown in Fig. *A*. An interesting characteristic of this room is that the temperature from floor to the 5-ft. level is controlled almost wholly by the temperature of the surrounding room, and is practically unaffected by the heat output from the radiator. The average temperature at the center of the room up to the 5-ft. level is found to be only about 2 deg. fahr. higher than the surrounding room. The average temperature at the ceiling is from 6 to 12 deg. fahr. higher than the surrounding room, varying with the heat output from the radiator.

All points of this test room will assume a steady temperature within an hour

after steam is turned on, thereafter rising or falling with change of temperature of the surrounding room. As might be expected from steady temperatures, the condensation rate from the test radiator has been found extremely uniform, permitting close duplication of tests when desired. It was anticipated that this room with warm walls, would yield less condensation than the *Class A* room with outside wall exposure. Tests proved, however, that condensation from the warm wall room checked closely with tests of same radiators at the Mason Laboratory in the *Class A* type of room, also with figures from the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS' GUIDE for the same size of radiator.

An interesting comparison was made later with the *Class B* room, using the

FIG. *A*. WARM WALL RADIATOR TEST ROOM AT MASON LABORATORY, YALE UNIVERSITY, NEW HAVEN

refrigerated test room at the Brabbée Laboratory through courtesy of the American Radiator Co. Five different cast iron direct radiators were chosen for these tests, of diverse sizes from 2 to 5 columns. One of the test radiators was of new panel design, of low height and great width in proportion to its surface. General particulars of the radiators will be found in Table 1, also the heat emission expressed in B.t.u. per sq. ft. per hour, per degree of temperature difference.

Comparison of the percentage differences in the last column shows quite close agreement in heat output for the four-column radiators, but considerable discrepancy for the special panel radiator, with larger figures for the warm wall room.

It can hardly be claimed that the difference found in this example indicates a defect in the principle of the warm wall room. It indicates, rather, that the

warm wall test room was too small for the radiator, which occupied practically the whole of one side of the room.

In view of this showing I think it fair to assert that a radiator test room of the type called *Class C* deserves consideration as a possible substitute for the test rooms denoted by *Class A* and *Class B*, having most of the advantages of the latter with none of their disadvantages. It has been charged that the warm air room with its openings into the surrounding room, has an unnatural air circulation which will influence the rate of condensation in the radiator. Our tests have failed

TABLE 1. TESTS OF CAST IRON RADIATORS IN WARM AND COLD WALL ROOMS
Heat output in B.t.u./sq. ft.-deg.-hr. at 1 lb. and 70 deg. fahr.

Columns	Height, Inches	Surface	Cold Wall	Warm Wall	Diff. p. c.
Two col.	45	40	232	236	1.7
Three col.	22	42	234	238	1.7
Four col.	27	40	241	247	2.5
Five col.	36	42	239	242	1.3
Panel, 7 ft. long	23	30	280	325	16.0

to show any such influence on the rate of condensation. There seems to be little ground for the charge that the circulation is unnatural in the warm wall room, since in either type of room the only circulation possible is for the warm air to rise above the radiator, being replaced by inflow from the lower part of the room, thus keeping up a steady gravity air circulation.

Referring to the questions brought up for discussion, I do not favor a new unit to replace 240 B.t.u. per hr. as the equivalent of 1 sq. ft. of radiation, for the reason that the latter unit already has been widely adopted for boiler and radiator work, and has been found fairly satisfactory in practical use. It would be unwise, perhaps impossible, to change it now. Probably the 240 B.t.u. unit is not more illogical than that for boiler hp., which has existed for many years in spite of efforts to introduce a new unit.

A standard method of reducing radiator heat output from any room temperature to equivalent at 70 deg. fahr. was described in the Report of the Advisory Committee on Radiation, JOURNAL of the Society, March, 1927, adopting a suggestion from Dr. Brabbée to conform to the best European practice and confirmed by experimenters in this country. If the actual room temperature is denoted by t and the steam temperature by t_1, the correction factor will be expressed by $\left(\frac{t - 70}{t_1 - t}\right)^{1.3}$. The correction factor will be a number of little greater, or a little less, than unity depending on whether t is greater or less than 70 deg. fahr.

Logarithms may be avoided in this calculation, if desired, by using an approximate expression based on power of a binomial, $(1 + x)^{1.3} = 1 + x + 0.3x$. To illustrate the application of the approximate method, suppose $\left(\frac{t_1 - 70}{t_1 - t}\right)^{1.3} = 1.05$. By logarithms, $(1.05)^{1.3} = 1.0655$. Approximate rule, $1 + 0.05 + 0.3 \times 0.05 = 1.065$. If the ratio is less than unity, the signs in the approximate expression will be negative, thus: if $\left(\frac{t_1 - 70}{t_1 - t}\right)^{1.3} = 0.95$. By logarithms, $(0.95)^{1.3} = 0.9355$. Approximate rule, $1 - 0.05 - 0.3 \times 0.05 = 0.935$.

I have heard occasional criticisms of the table of conversion factors in Chapter II of THE GUIDE, saying that the factors were too small. That there is some reason for this criticism can be seen from inspection of almost any part of the table. For example, for steam temperature 215 and room temperature 80 deg. fahr., the factor in THE GUIDE for reducing heat output to 70 deg. fahr. room temperature is 1.064. In this case the ratio of the temperature differences is 1.074 and the value $(1.074)^{1.3}$ is 1.096. It will be hard to explain a factor lower than the temperature ratio 1.074.

S. R. LEWIS: I am going to ask permission to interject a little thought of my own about this matter of the Kent. It is difficult to tell just what I did mean when I proposed this new term. I sympathize with Dr. Brabbée. I don't believe in being conventional. His continued reiteration of the discovery that we can get more comfort out of a radiator and condense less steam in that radiator than we can with some other radiator appeals to me. This proposition of a Kent, then, is simply an expression of the efficiency of a radiator in terms of comfort. The term is just a short-cut and it will be helpful if we can conceive the comfort effect of the heat given off by a radiator.

DR. C. W. BRABBÉE: We are very much in favor of what Mr. Houghten suggests, however, there may be some difficulties arising from the kind of test room used. I would like, therefore, to make some additional suggestions, but before doing so I refer to Mr. Houghten's statement that one of the first questions to be studied will be if the condensation is actually a measurement for human being comfort. I am sure, after considerable study, Mr. Houghten will reach the conclusion that the condensation is not a means for judging human comfort, and from this moment on the real investigations and real progress will start.

We actually do not know what heat is and how heat influences the human body. Therefore, we should be very careful and should not erect in those test rooms theoretical walls which are not used in practice. I mean we should not use steel walls, but walls of a practical nature. And for the same reason I think there should be windows in those walls because the air currents on the windows influence very much the comfort feeling. From all the reasons discussed this afternoon I think those investigations will have a much greater benefit for the Society, the industry and the public if *comparative* instead of *absolute* tests are made, because only comparative tests can eliminate the influence of the dimensions and the special set-ups of a single test room.

In introducing Konrad Meier's paper, Mr. Lewis said that he cannot prove it but according to his feelings we are right in the principle that different radiators of different designs can give more comfort with less fuel consumption and I am very glad that this feeling prevails.

R. V. FROST: The authors propose a new term, the new unit, Kent, to be used in rating radiators in place of the present equivalent square foot unit. I wonder if they really intend to state it just that way. It seems to me that if we use a new term, it must be distinguished from the square foot unit. That is, the square foot unit must be retained but the new unit will be used to designate the heat output; or the radiator output instead of the input.

MR. LEWIS: The radiator output expressed in comfort.

DR. BRABBÉE: The useful radiator output.

MR. FROST: Then, if we use the word Kent to express comfort, does that mean efficiency? Are efficiency and comfort the same thing?

I think it will have to be considered as nebulous as Mr. Lewis has expressed it until we come down to a definite idea of whether there is a difference between comfort and efficiency. Mr. Fansler says, "What is comfort anyway?" These are questions that we have been studying in radiation and they must be settled before we can tell very much about determining what a new unit represents. So this expression "Kent" is something, as Mr. Lewis says, that is quite nebulous. We cannot decide upon it now. We have too many questions to settle in regard to what takes place in a radiator; that is, what is radiator performance, before we can settle upon a term such as the word "Kent" implies.

R. C. BOLSINGER: The question of the method of testing radiators and the question of rating radiators, I think, should be separated. We have our code which was adopted which shows 240 B.t.u. value equivalent to a square foot of heating surface. Well, the engineer and the industry do not seem to have accepted that basis of rating radiators. In other words, the trade seems to have gone back to the idea that a square foot of radiator surface means 144 square inches and not 240 B.t.u. Several of the radiator manufacturers have got out the new tube type of radiator and have rated their radiators on the 240 B.t.u. equivalent, showing it in their catalog on that basis, and what has been the outcome? The heating contractors and engineers will not accept it. So a lot of them have gone back to rating the radiator on the standard basis of 5 ft., $3^1/_2$, 3, $2^3/_4$. So I think this is a question that ought to be given consideration. It is all right to rate a radiator or test a radiator and give a total B.t.u. output, but I think the engineer and the heating contractor who installs it is looking for something simple and he is satisfied with the 5 ft., $4^1/_2$ or $3^1/_4$ ft.

F. D. MENSING: The question before the house as I see it, as far as comfort goes, is, how is the heating contractor and how is the engineer going to figure out comfort under those conditions? The same radiators, but two different rooms. How many jobs does the engineer get that are alike? I don't think we are at the point where we can start to talk comfort until we know what our radiator itself will do.

We figure the loss of a room or a mill or an apartment in B.t.u. and just as many B.t.u. must be put into that room as are lost to the outside. The question of comfort is something that should come later. Comfort is something I know nothing about. If you put 60 people in a room you will get 60 answers regarding comfort. What we all want to know is how many B.t.u. a particular radiator will give off. We can rate an electric motor; we have no trouble in doing so; we measure input and output and we don't care whether it is going to be hitched up to a loom or a blower; we don't worry what kind of a room we are going to put it in. The electrical engineer knows where he stands, but there isn't a man in this room that knows where he stands on a radiator. As I view the situation, the manufacturer of that radiator is entitled to all that radiator will do; no more, no less; and what it will do is the amount of heat it will throw off, we will say, in a 70 deg. atmosphere setting clear and free. Then as engineers it is up to us to figure

factors of safety for different locations. I think the whole problem is one of factors, but we will never be able to get factors until we get maximum output.

The Society's Boiler Code Committee with whom I did not agree at first but I at least had brains enough to keep my mouth shut, I now agree with absolutely. Their code plans to bring out all that a boiler will do and the manufacturer is entitled to credit for all that boiler will do. If the engineer can't get the maximum output from it, that is his fault. How is a boiler manufacturer going to know where that boiler is going to go? There is only one man that does, or should—the man who is going to put it in. The same is true of the radiator. We have got to find out what the radiator will do when operating under maximum conditions, but if we attempt to test radiators under every possible room and structural condition, nobody here is ever going to get the answer, neither are our children's children.

PRESIDENT ANDERSON: That is putting this matter off some time. Mr. Howell, I would like to have you say something on this subject as you have been identified with this question of testing radiators for a great many years.

F. B. HOWELL: I would like to observe that no two vertical inches of any heating radiator's height have the same heat emitting value. The first foot from the floor of a radiator does about three times the work that the third foot does and the second foot proportionately. These are not exact figures, but the third foot from the floor has much less air warming value than the first foot, though each foot of surface of any radiator embodies the same quantity of metal—and costs equally as much to make.

The surface in a heating boiler is a typical example. A boiler might have 100 sq. ft. of heating surface, 10 ft. of which might be the crown sheet, 20 ft. of which might be the roof of the flues, and 20 ft. of which might be the floor of the flues. You might specify the crown sheet surface 100 per cent for heat transmission—the roof of the flue galleries 40 per cent—and the floor, especially if thickly covered with soot, which is usually the case, zero; and yet the boiler has 100 sq. ft. of heating surface. It is about the same for the radiator. Let's distinguish the radiator's efficiency by its literal heat emission in B.t.u. The factor 240 has been the equivalent since the beginning of the heating industry and has met every requirement. Let it continue to be the B.t.u. divisor for determining the steam radiator's equivalent square feet of heating surface.

A. A. ADLER: My remarks refer to the unit Kent which has been proposed. In view of the confusion as to the meaning of comfort and the difficulty of its measurement I think that the definition of the Kent should be deferred to some future time. The analogy brought out by Mr. Mensing, between the electrical motor and the radiator, is not comparable because the unit by which we measupe the electrical input and the energy output is well defined and not subject to opinion while comfort is. The Research Laboratory has done valuable work in establishing the Comfort Zone. But this zone is subject to correctior for clothing worn, activity engaged in, health of individual and mental attitude—an intricate collection of factors. As a consequence it may be a long time before we get a yardstick by which comfort is measurable and then its definition as well as the unit will be in order.

J. F. MCINTIRE: Mr. President, it doesn't require any more discussion on this subject on which we know so little. We haven't experimented enough in our laboratories to draw accurate conclusions. This subject is in the hands of an Advisory Committee which is giving it a lot of thought and I think we are all willing to abide by their decision in reference to determining a Kent.

MR. LEWIS: You are going to have a lot of fun with me about the Kent, but five years from now you will still be interested in something of the kind. The purpose of presenting this paper was that the committee, the Technical Advisory Committee on Radiation for the Research Laboratory, should get your criticisms and suggestions. Mr. Mensing is the chairman of this technical advisory committee and we request that you communicate with him and tell him anything you can that will be constructive toward the equipment which we are about to build for testing radiators.

M. W. EHRLICH: I don't know that my thoughts on testing or rating radiators would have any bearing, but I do believe, as was brought out here, that there is quite a bit of confusion in some of the things said because of not labeling the form of radiation involved, which may have been expressed in another way as to location and application. But I do believe that sometime in the not far distant future we may reach a point where we will establish a height at which to measure radiation more nearly in line with room occupancy, such as Dr. Brabbée points out, and on that basis possibly the condensation would be a factor and not the square feet or the other way around, the heat output per pound might be the result, although you would have this very vague factor of comfort to be considered.

W. L. FLEISHER: I want to say a word on the practical side of this question. The subject is of practical interest to the heating contractor and the discussion that we have had this afternoon I don't believe helps the contractor in any way. There are on the market today about seventeen or eighteen varieties of new type of radiators. Whatever one manufacturer does in the way of making his radiator efficient, that is with fins or something else to drive the heat out to a particular zone in the room, will undoubtedly be duplicated by the next one. Consequently any advantage that the one manufacturer might obtain would soon be obtained by the next one and the heating contractor would be in the same position that he is in now with boilers and other things in the field where one manufacturer indicated that his apparatus would do certain things that another one wouldn't.

I have a strong feeling that the discussion that is developing today is only going to retard and befog the innocent purchaser in the comparison of the different radiators that are on the market or that are coming on the market, and that a uniform method of figuring the condensing rate of the radiator, leaving the function of veins or diffusers or anything of that kind to a future time, is what the contractor needs today and the thing that our Research Laboratory should decide upon so that the actual radiator as it exists today under the same conditions may be tested at once without discussion as to new ideas of comfort. In this way the contractor will be benefited by the work of the Research Laboratory.

MR. FROST: May I say a word in answer to the last speaker's remarks? I don't think that the contractor needs to take very seriously what has been said

this afternoon about radiator performance. That is, not this generation. What had been said has been for the benefit of those who come about 15 or 20 years from now. Our present ideas of comfort and radiator efficiency will not be changed by the new type of radiation. As far as the designing of new types of radiation we have not reached the point where we can consider the idea of comfort to any great extent. So don't look too seriously on what has been said.

F. C. HOUGHTEN: Before closing the subject, I would like to point out more definitely that our unwillingness to accept heating effect, comfort effect or heating efficiency of radiation to be reflected in rating at this time should not be considered as failure to appreciate its importance to the heating industry. What I do want to emphasize is that we do not yet know enough about heating effect to make use of it in rating radiators. Dr. Brabbée has shown that a certain radiator which we will call "A" will satisfactorily heat a certain room with half the amount of steam. That is well and good. It will do it without question under the conditions of his test. Will it do it under all other conditions in different rooms? There is reason to doubt whether the two radiators would show the same relative heating effect under all conditions.

If that supposition is true and a certain contractor should install radiator "A" with a rating twice as high as the radiator with which it was compared, in a condition where it is not twice as good as the second radiator, he would be out of luck.

Heating efficiency of radiators is a question that is of great importance and we must study it, but we cannot let it reflect itself in ratings until more is known about it. Neither can we accept Dr. Brabbée's results as universally applicable to all types of radiators and forms of space to be heated.

DR. BRABBÉE: Without having a goal you can't proceed properly. The goal was to prove that certain types of radiators will give certain effects with less surface, with less condensation and therefore with less fuel. This new result, we think, has been positively obtained. As far as the heating contractor is concerned, he need not be disturbed, because behind the rating figures given stands the guarantee of the maker.

No. 790

PRACTICAL VENTILATION FOR SCHOOLROOMS

By S. R. Lewis,[1] Chicago, Ill.
MEMBER

THE purpose of this paper is to describe a rational arrangement, which it is believed will be capable of giving the best results practicable of attainment, either when using windows for fresh air supply or when using a supply of unheated air from other sources than windows in classroom ventilation.

The New York Commission on Ventilation has advocated windows open from the bottom, with deflectors to divert the entering air upward, and with radiation controlled by thermostats below all windows used for ventilation. It has recommended a considerable increase in direct radiation beyond that needed for structural heat losses, to care for the air-change due to the open windows, and has recommended gravity vent flues with exhaust openings from the room at or near the ceiling of the side wall opposite the intakes.

The New York Commission has refrained from going into much greater detail than the foregoing. The greater detail is, of course, the province of the heating and ventilating engineer, who ought to be able to devise satisfactory physical arrangements after he has been made to understand the purpose of the arrangements, or has been told the underlying principles of the process.

The earlier field studies of the Commission were restricted to comparisons of health and comforts in window-ventilated rooms on the one hand, and in mechanically ventilated rooms on the other. Having demonstrated to the satisfaction of the members of the Commission the superiority of the window-ventilated rooms on these two counts, and pointing out that the main difference lies in the fact that the air of the fan-ventilated room is likely to be about 20 deg. fahr. higher and more uniform in temperature and that the air movement in this method is considerably greater, reported (Ventilation, p. 528 of the New York Commission Report):

> "We are forced to conclude that window ventilation with ample direct radiation, window deflectors and adequate gravity exhaust, seems the more generally promising method for the ventilation of the classroom where local conditions permit its use". . "on the other hand there will be many schools in which this method cannot be applied. Where noise and dirt and odors from the street make it inconvenient to have windows open, the use of the plenum system would, for instance, be clearly indicated."

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[1] Consulting Engineer, Chicago, Ill.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

With these few exceptions, this amounted to a rather general condemnation of mechanical ventilation in schools, and it constituted a challenge to the engineer to improve upon, or at least to duplicate, the health and comfort conditions attained with window ventilation.

The recent studies of the Commission at Syracuse and elsewhere indicate an

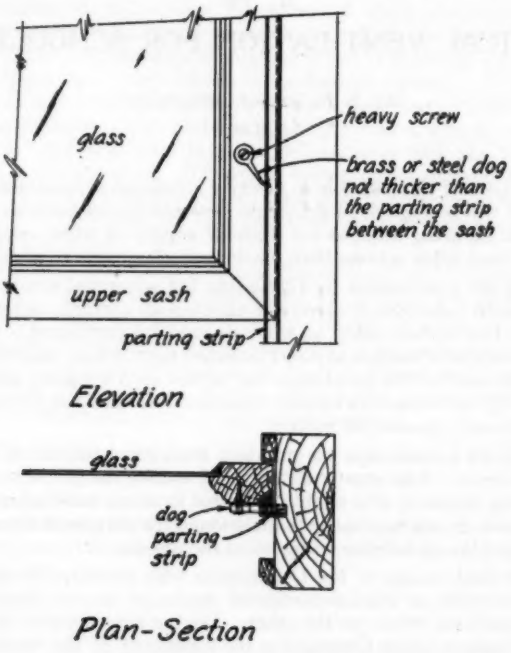


FIG. 1. SHOWING DOG FOR HOLDING UPPER SASH IN PLACE INDEPENDENT OF LOWER SASH

honorable and conscientious endeavor to learn the truth. In this effort to learn the truth every heating and ventilating engineer will join with all his heart.

There seems to be some yet unproved health quality in the environment of the pupils in naturally ventilated classrooms, particularly where the air supply has not all been heated by passing over heated surfaces.

Any unprejudiced observer who sees the records, the probity of which cannot be questioned, must consider them very seriously. These records seem to show evidence of a mysterious influence in classrooms which have no tempering heaters and which use gravity or window air supply, which influence seems to reduce

complaints and absences from colds in the head, or which, expressed more euphoniously, reduces the incidence of respiratory diseases.

Granting that the health of children in the naturally ventilated rooms is superior and assuming that it is due to some hitherto undesignated agency, the reasonably possible agencies are:

A. Consistently maintained lower temperature.

This has been fairly well eliminated as the probable cause of superiority, since where the outside air supply came into the rooms without ever having passed over warm heaters the superiority persisted, even though a higher average interior temperature was maintained.

B. Ultra-violet or other invisible rays ordinarily stopped by common window glass.

This has been fairly well eliminated, since even with the open window rooms the shields over the openings nearly always prevented any light from entering the rooms without being filtered through glass.

C. Reduced motion of air.

An air change of once in fifteen to twenty minutes in a schoolroom such as is in effect usually with gravity-indirect systems necessarily gives much less physical contact with the bodies of the pupils than an air change of once in seven or eight minutes, the usual rate when 30 cu. ft. per pupil per minute is supplied. With the reduced volume of incoming air there is much less danger of rapid cooling of an over-warm body, and so perhaps less danger of causing a person to catch cold or feel chilled. It is possible that herein lies the mysterious influence.

D. Unheated air supply.

In all of the observed rooms where superiority persisted, the entering air was tempered by admixture with warmer air rather than by rubbing over hot radiators. Much of the time the relative volume of this entering unheated fresh air compared with the volume of the very hot recirculating room air was small. Yet it is possible that the mysterious influence is present in the small volume of unheated air supply carrying the "vital property" suggested by Hartmann.

E. Physical stimulation due to continual and rather rapid temperature-variations.

In the observed rooms where superiority was noted, even though automatic temperature control might be in evidence, there were considerable temperature-variations due to manipulation of the windows and control valves. We seem to enjoy gentle breezes and we come in with flushed cheeks and tingling hands after exercise out of doors on a cool day. It is possible, though, that the mysterious influence is inhibited or nullified when the person stays for some time in a steady, uniform temperature, even though that temperature may not be too warm or too cold for comfort.

Not much in the way of a clue to the mysterious influence outside of the five above possibilities is to be found, though age, race, stock or other conditions may yet be found unexpectedly to govern the striking results which have been noted.

One must remember that Doubting Thomases had a grievous time believing that mosquitoes were the mysterious influence in malaria and yellow fever.

We are in a way to exhaust possibilities of the five reasonable hypotheses outlined as they are being attacked at several points from many angles.

However, it seems worth while at this time to outline the sort of heating and ventilating plant which could, in the light of the best present knowledge, be operated so as to be most favorable to all of the conditions set forth.

These specifications may be divided into three groups: those serving small schools having up to four classrooms; those for schools having from four to twelve

classrooms; and those for larger buildings having a considerable number of classrooms on many stories with auditoriums, gymnasiums, laboratories, etc. These divisions are arbitrary, having, however, some influence on cost, space for pipes and ducts, orientation, etc.

For the small rural school of one or two classrooms, where presumably fires will not be maintained continuously, and there would be danger of freezing—and where, incidentally, installation costs are a most important item—it is apparent that the jacketed stove and the warm air heater with provision for the admission of an adequate supply of fresh air will continue to be the preferred means of heating and ventilation. The warm air heater with gravity exhaust is perhaps the most prac-

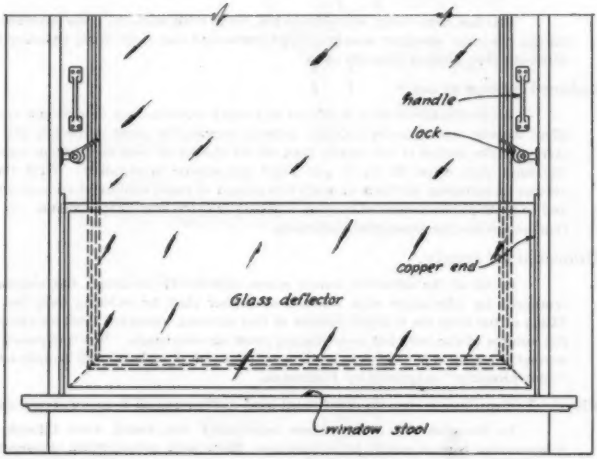


FIG. 2. ELEVATION OF LOWER SASH SHOWING HANDLES ABOVE DEFLECTOR AND SIDE LOCKS ACCESSIBLE FROM FLOOR

tical system for rural schools of from two to four or six rooms. The window system of ventilation is not feasible in this type of building.

For schools of six classrooms or more, we may assume that straight-forward window ventilation, with direct steam radiation and gravity vent flues, may reasonably be installed.

All of the windows along the side from which light is obtained, to the left of the pupils, are to have the lower sash arranged for air introduction.

The conventional sliding double-hung type of window may be used, with glass deflectors, say 12 in. high in wooden or metal frames, resting on the window stools. The upper sash should be blocked tightly in place, as they do not need to be moved.

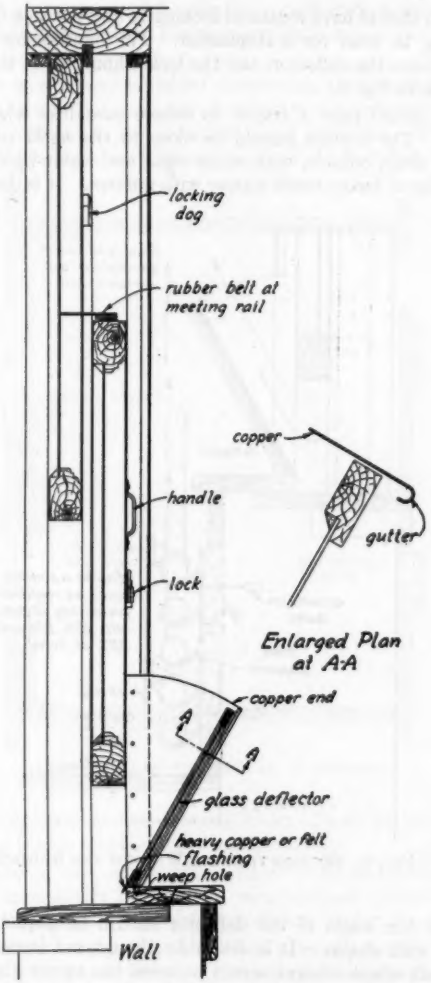


FIG. 3. DETAIL OF WINDOW AND DEFLECTOR DESIGNED TO REDUCE AIR AND STORM LEAKAGE

An effective method of doing this is shown in Fig. 1.

There are doubtless many other easy and satisfactory methods of holding the upper sash in place independently of the lower sash.

The lower sash should have means of locking in any position desired without the operator needing to send for a stepladder. The handles for moving the lower sash should be above the deflector, and the locks should be at the sides of the sash, perhaps as shown in Fig. 2.

The deflector should have a frame, to reduce casualties which occur with unprotected glass. The bottom should be close to the outer edge of the window stool and should drain outside, with an air-tight and water-tight bottom and ends. The ends might be of heavy sheet copper with gutters. It is desirable, though not

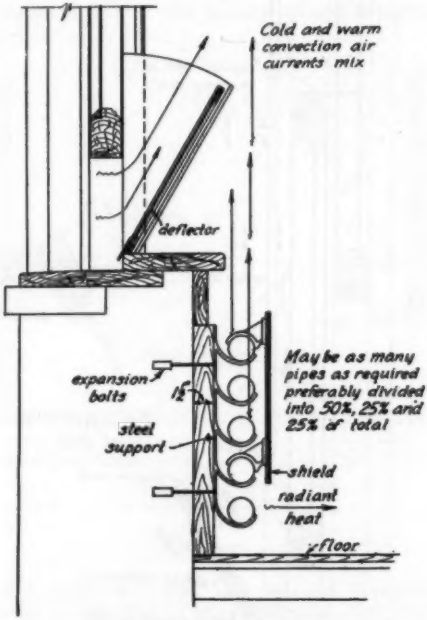


FIG. 4. SECTION THROUGH WINDOW AND RADIATOR

imperative, that the angle of the deflector should be adjustable. This can be arranged easily with chains. It is desirable, though not imperative, that leakage through the crack which always occurs between the upper glass and the meeting rail be kept at a minimum. A piece of rubber belting screwed to the top of the lower sash and just touching the glass of the upper sash will accomplish this. (See Fig. 3.)

The scheme seems to demand double-hung sliding sash, with delicate adjustment of height of inlet openings.

The fundamental of the window-scheme of ventilation is that there shall be under

each fresh air inlet a radiator which preferably shall have a shield in front of it, and that enough radiation to warm the entering air to some extent shall be heated at all times.

In mild weather in window-ventilated classrooms, even with thermostats (and it is unlikely that thermostats will be provided in the country) there is a great tendency toward overheating, due to excess direct radiation. Yet, with window-ventilation when there is need of any heat at all, it is surely needed under *all*

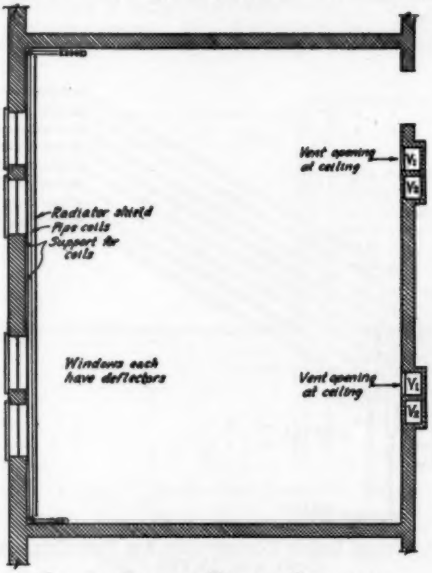


FIG. 5. PLAN OF TYPICAL CLASSROOM

windows used for ventilation. An excess amount of heat under one window inlet and none under the others is exceedingly unsatisfactory.

Therefore, a more or less continuous radiator is needed under all the intake-windows, divided horizontally into several superimposed radiators rather than to have the conventional separate complete radiators under the several windows.

Fig. 4 illustrates this arrangement and also shows the shields. All direct radiation in classrooms should be shielded. These should be supported, say, 2 in. away from the hot surfaces, and should be made of two layers of metal with insulation between. A satisfactory shield can be made of No. 26 gauge galvanized steel and 1/4 in. thick asbestos mill board, with bright tin against the radiator. The bottom of the shield may reasonably be kept about 6 in. above the bottom of the radiating surface, so as to permit some radiant heat to reach the feet of the children in the nearest aisle.

In Fig. 5 is shown the plan of a schoolroom, with the various arrangements for an approved type of pure window ventilation. The radiation should be arranged as shown in Fig. 6.

The pipe coils in Fig. 6 are necessarily used with a two-pipe system of steam or water circulation. Such an arrangement for gravity steam requires that the returns from each room shall be brought separately to a point well below the boiler-water line before being connected together. If a vapor system is used with thermostatic traps, the return valves shown in Fig. 6 may be omitted, and the traps may take their place.

If automatic temperature regulation is installed, one diaphragm valve may be

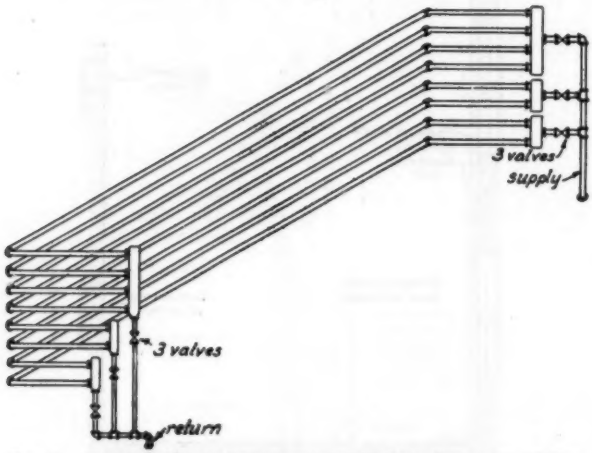


FIG. 6. TYPICAL STEAM CONNECTIONS FOR PIPE COILS, 50–25 PER CENT AND 25 PER CENT

nstalled on the boiler side of the three hand-operated supply valves shown, but these valves may not be omitted. By keeping one or the other of the three divisions of radiation shut off it is easy to prevent overheating in mild weather, even though there is a great excess of radiation for such weather.

The vent flues should go out as separate flues in chimneys which extend well above the highest points of the roof. Several of these flues may be grouped together of course, but they should be separate all the way.

Metal ventilators are less satisfactory than chimneys for the vent outlets. Revolving type metal ventilators are to be preferred to fixed type metal ventilators. A separate ventilator should be provided for each room when ventilators are used, and they must be high enough above the roof that eddy currents or back-drafts shall be avoided.

The outlets from the rooms should have tight fitting, easily operated registers

or dampers at the outlets, which can be closed to prevent waste of fuel when the building is not occupied.

For a larger type of school, it is probable that the mysterious influence due to unheated air supply or reduced air volume may be gained in the following rather more simple manner.

There are to be provided adequate supply flues as well as vent flues.

The partitions between these supply flues and the vent flues for at least 6 ft. of each may be of one thickness of uninsulated sheet metal, so that either flue which is warmer may warm the cooler one. It is desirable to have at least two pairs of

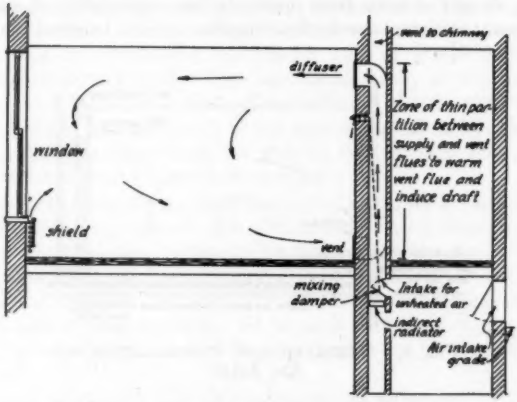


FIG. 7. GRAVITY DIRECT AND INDIRECT SYSTEM

such flues for each standard size classroom, since it is then easier to secure diffusion without drafts.

A better arrangement for warming vent flues is to install small radiators in them, accessible through doors in the flues, and protected by canopies or offsets against moisture falling from above. The old-time gravity-indirect plants of this general type used small coal or gas fired stoves to warm the vent flues and so to insure a steady draft up them.

The vent openings from the rooms are preferably at the floor and adjacent to the supply flues, so that they may be heated a little, so as to have draft. The supply flues are arranged with indirect radiators at their bases with cold air intakes and by-pass dampers, either automatic or manual, as shown by Fig. 7.

The indirect radiators are heated nearly all of the time and control of ventilation is by manipulation of the mixing damper which allows more or less unheated air to enter, induced by the injector-like effect of the warm air from the indirect radiator.

The same pipe coil arrangement of the radiation in the room, under the windows, shown in Fig. 6 is desirable, though it is not necessary with this plan to have any

great excess amount of direct radiation. The shields in front of the direct radiation are equally important.

With this scheme it is desirable probably to have the windows so arranged that they can be lowered easily from the top, for additional fresh air intakes or for outlets for surplus heat when desired. When the wind direction permits, an extension thermometer projecting into the supply flue is highly desirable so that the temperature of the entering air may be observed and regulated. The vent openings should have registers or effective arrangements so that they can be closed at night to prevent unnecessary heat loss.

For still larger schools, where the diversified kinds of rooms, many stories, difficult surroundings, danger of noise from open windows, desirability of air filtering devices, etc., seem to warrant mechanical ventilation, it is believed that the desired

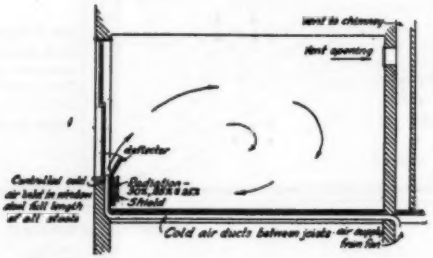


FIG. 8. MECHANICALLY CONTROLLED COLD AIR INLET

condition would be obtained by an arrangement like Fig. 8. One supply fan may be installed per room or many rooms may be served by one supply fan.

The vent openings, Fig. 8, may be near the ceiling, though it is not entirely certain that floor openings would not serve as well.

With this scheme, the room-effect presumably will be consistently as favorable as that intermittently to be obtained with window-gravity inlets, even when the latter is operating under most favorable conditions and there is a gentle wind pressure coming in through the window.

With this mechanical system, the supply of unheated air is always positive, whereas with the window inlets it is often questionable or negative.

In other particulars the arrangement for mechanical air supply as per Fig. 8 simulates that for uncontrolled air supply. The radiator divisions, the shields, deflectors of Fig. 8, are arranged to give the same effect as those of Fig. 4.

It appears that the mechanically delivered supply of unheated air, entering the room in such manner as to insure very even diffusion, should prove more satisfactory in nearly all school buildings than will the gravity inlet at the window, affected as it must be by every variation in wind.

The arrangement shown by Fig. 8 is, of course, easily susceptible of combination

with all of the conventional modern devices for air conditioning peculiarly adapted for central fan systems, and which are not adapted to the window inlets or to the gravity indirect systems. With the mechanical supply the air may be cleaned of dust, or be ozonated without heating it. There may be tempering heaters for use in very cold weather, and after tempering the air, if proved desirable, artificial moisture may be introduced. If the air volume and movement shall be proved to have gone to the other extreme from the present 30 cu. ft. per minute per pupil practice so that more movement is needed, part of the air may be recirculated.

From the standpoint of ultimate flexibility and adaptability the scheme shown in Fig. 8 commends itself.

The admission of some unheated air is now being achieved by many of the unit ventilators, with their mixing dampers. Some question is raised, however, as to whether one unit ventilating machine per room gives sufficient air-diffusion, and the Syracuse studies suggest that one machine may give so high an outlet velocity as to favor rather than reduce the prevalence of respiratory affections.

It is possible that some part or all of the mysterious effect for which engineers have been seeking the cause may be due to the physical stimulation which results from rather sudden temperature variation.

The designers of automatic temperature control are ready to furnish thermostats which will accomplish any desired cycle of variation. It is a simple and reasonable, mechanical or electrical task to arrange for such a variation, and it is hoped that there may be developed, ere long, some experiments to check this possibility.

The location of the thermostats in the rooms is of vital importance with any of these cold-air-introduction schemes. As far as is known the thermostats need to be where the air current passes over them as soon as the two currents, warm and cold, have met.

There is great probability that it may be found expedient to install on the window inlets, of the original New York Commission plan (shown in Fig. 4), perhaps at the tops of the inclined glass deflectors, automatically controlled balanced dampers, so that the thermostat will close or open these dampers simultaneously with its manipulation of the supply valves to the radiators. It must not be forgotten that window-inlet ventilation requires that the radiator under the window shall have enough heat output to temper the cold intake-air, and combined with the effective heat output of pupils, ultimately to neutralize the cold intake-air.

The original report of the New York Commission has been interpreted as setting forth arbitrary rules for the size of classrooms, although it does not require specifically that the room sizes shall be increased. (See Winslow's note in JOURNAL OF AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, May, 1927, p. 326.)

If window ventilation does give superior health results it gives these results because of some single inherent physical property of window ventilation, or because of some group of such properties, and certainly these properties do not appear to depend on any particular minimum space-per-pupil requirement.

In a general way the cost of ventilation, whether mechanical or gravity type, is proportional, both in first cost and in operating cost, to the amount of air handled.

No window or gravity system of ventilation can be depended upon to handle any specific volume of air.

Taking into consideration the equipment required for consistent window-supply ventilation, there is no very great difference in first cost between it and a mechanical system. In this consideration the Commission has demonstrated conclusively that in order to be operable, classrooms with window-supply ventilation must have excess radiation, automatic control, deflectors, vent flues which are positive in action and should have radiator shields.

It is well known that if a consistent and specific volume of air must be handled most economically, the necessary energy to move the air will cost less and be more satisfactory via an electric motor than via a heated chimney.

Granted that around 67 deg. average temperature is to be maintained in the classroom, we must expend for ventilation whatever amount of heat is required to raise the entering air to a temperature which will be comfortable to the pupils.

When considering relative differences in cost of labor for operating these various types of ventilation, time studies should be made to determine the influence on teaching efficiency of the more or less constant adjustment of windows and dampers required by the gravity-window systems, as well as the actual money value of the time given by the teachers to adjusting ventilation.

The deduction can be made reasonably, regarding first and operating costs, that there is not enough difference between any of the three general methods described, in the two building-size zones where they overlap, to be of any particular moment.

As soon as further study shall have developed specific requirements, or shall have divulged the much-sought mysterious influence, a coherent scheme for obtaining that influence will be available quickly.

As of the winter of 1927–28 the foregoing schemes are believed to express, each in its zone, ways in which to achieve the mysterious influence.

If it can be demonstrated to attain equal health results, the mechanical arrangement, with its positive air delivery and accurate control, coupled with its diffusion virtues and its flexibility, is believed to be the most reasonable and logical type for ordinary investment.

DISCUSSION

PROF. F. L. FAIRBANKS (WRITTEN): Your paper is of very great interest to me for it appears that you are very near the solution of the problem and I believe that what we have learned at this station in regard to air movement in dairy stables will be of interest. The mysterious influence or undesignated agency I feel may be the more complete diffusion of the fresh air with the vitiated air.

On page 97 of your paper, agencies *C* and *D* express the factors which influence this undesignated agency or internal air movement. The entering air falling through the warm room air diffuses more readily than would air of a higher temperature. Admitting cold air might also influence the absolute amount of oxygen in the room.

In our dairy stable investigations where each observer worked 12 hours a day and at times for 8 hours continuously in the stable, the effect of different air conditions was very noticeable on ourselves and the barn men.

In cases where the air movement into and out of the stable was at a definite

rate, but with a minimum of diffusion, our systems became congested after 3 or 4 hours work. With the same air movement but complete diffusion we have been able to work 8 hours without any noticeable effect.

One simple illustration may suffice. In the first case cited, when one passed from the stable to the outer air he involuntarily took a deep breath of the outdoor air. In the second case, this action was entirely absent. One passed back and forth from stable to out of doors or *vice versa* with no noticeable difference in the depth of breath, the only effect being that of difference in temperature.

We have found that windows are not satisfactory as intakes, the opening usually being too large, difficult to control and not suited to properly direct the incoming air. The ceiling inlet also permits greater and more rapid diffusion and by proper directing of the incoming air eliminates drafts.

To avoid rapid variation of temperatures, we have found the floor outtake best and also that by properly insulating the outtake flues we do not need to heat them. With only moderate insulation the temperature drop in a 50 ft. flue with an air velocity of 200 or 300 ft. per min. is never more than 2 deg. fahr.

On page 103 you indicate that the outtake should give up heat to the intake. In our work we make every effort to avoid heat loss to the outgoing column of air.

In regard to the wind effect on the intakes, engineers of the Louden Machinery Co. have designed an automatic intake which is working out very well in stables.

On page 104, in regard to vent openings I feel that the floor opening will prove most desirable.

On page 105, in regard to a gravity system handling a specific volume of air, our work seems to indicate that it can.

Our theory, that, by destroying the velocity of the incoming air, causing it to fall of its own weight through the warm stable air and by stimulating convection currents to assist in the diffusing or mixing of the fresh air with the stable air, we insure a uniform degree of purity of air throughout the ventilated space. This complete mixing accomplished, we should remove the mixture at the floor level in order to conserve the heat in the room to avoid sudden changes in temperature. The floor outtake also will not disturb the convection currents.

This theory to me is quite contrary to what little I know of present practice in which the breathing line or zone is stressed. My point is that the breathing zone should include every part of the ventilated space from ceiling to floor and from wall to wall.

I feel that this theory can and will be applied to the ventilation of shelters for man. This feeling and your paper are the reasons for thus addressing you.

No. 791

EFFECTS OF MECHANICAL AND NATURAL VENTILATION ON THE HEALTH OF SCHOOL CHILDREN[1]

By THOMAS J. DUFFIELD,[2] NEW YORK, N. Y.

MEMBER

Since this paper was written (December, 1927), the author believes to have recognized, in subsequent Syracuse studies, variables that were entirely overlooked at the time, namely, the size of the school, the area of the school district, and, consequently, the average distance the pupils had to travel to school.

The old, furnace-heated, naturally-ventilated schools which made the lower records of absenteeism and of respiratory illness were in the more densely populated sections of the city and had but 8 to 12 rooms. The modern, steam-heated, mechanically-ventilated schools served less populous areas, and had from 16 rooms upward.

Examination of the school districts showed that the average of the maximum distance pupils had to travel to the little, old schools was 0.22 miles, while that of the larger, newer schools was 0.40 miles.

The association between precipitation and respiratory illness among the pupils was brought out in the paper. The fact that the pupils attending such schools had greater opportunity for exposure to rain and snow, may explain the higher rates of respiratory illness reported from the larger, modern schools, which happened to have fan ventilation systems.

WITH the revival of the Commission in the autumn of 1926, it was the first thought of the members to test whether the findings of their field studies, conducted in New York City Schools from 1913 to 1917, held true at a later date and in different localities. In the selection of the field for current studies, the fortunate relationship between the Commission and the Milbank Memorial Fund, which is financing the work of the Commission at present as it did in the past, has shown itself a valuable asset. It was because the Milbank Memorial Fund is collaborating with the local health and educational authorities of Syracuse in what has become known as a "health demonstration" that that city was selected for the study.

With the cooperation of the Syracuse health and school officials, and particularly

[1] Tentative results of the school ventilation study in Syracuse, N. Y. Conducted by the New York Commission on Ventilation during the school year 1926–1927.

[2] Executive Secretary, New York Commission on Ventilation, 370 Seventh Ave., New York, N. Y.

Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, January, 1928.

the school health service, six schools were chosen—three modern mechanically ventilated buildings and, in lieu of window-gravity ventilated schools, three old furnace-heated, naturally ventilated buildings constructed 40 and 50 years ago.

To aid in the identification of these schools when considering the findings of the study presented later in this paper, the names of the schools, roughly classified according to type of ventilation, together with the number, the average age and the percentage of pupils of American parentage are given in Table 1.

It should be stated here that wherever an average value is given in this paper, due consideration has been given to the different numbers of readings or individuals. Every mean value is a weighted mean. There are no averages of averages.

In selecting buildings no attention was paid to the age, sex or nationality dis-

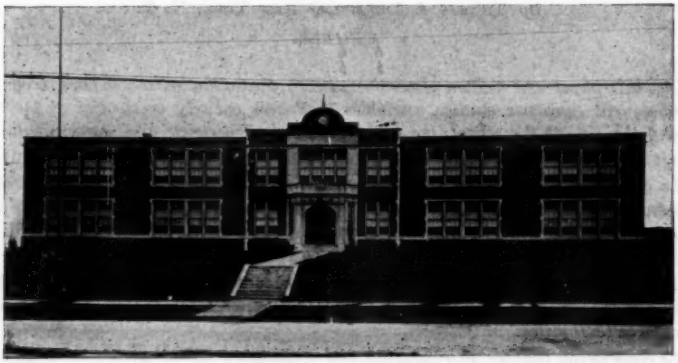


FIG. 1. SALEM HYDE SCHOOL, SYRACUSE, N. Y.

tribution of the pupils. Aside from the first classification of three mechanically ventilated schools and three naturally ventilated buildings, selection was made simply because the attitude of the principals toward health studies in their schools had always been favorable.

The six schools are all two stories high with brick exteriors. There is no air washing or artificial humidification in these schools.

The three modern, mechanically ventilated buildings have all been built within

TABLE 1. SIX SYRACUSE SCHOOLS USED FOR VENTILATION STUDIES

Name of School	Number of Pupils	Average Age of Pupils	Percentage of Pupils of American Parentage
		Mechanically Ventilated	
Salem Hyde	146	8.3	91.8
Seymour	707	11.1	62.0
Danforth	379	9.5	85.5
		Naturally Ventilated	
Montgomery	325	9.9	65.0
Merrick	232	8.9	91.4
Townsend	237	8.2	4.6

the past five years, and are of fire-proof construction, the rooms being lighted from one side only. Heating is accomplished by a split system; fresh air for ventilation is drawn in through a shaft opening above the roof. The air is warmed over indirect radiators and is forced into the rooms by fans.

Supply inlets, of which there are generally two per room, open some 8 to 10 ft. above the floor in the wall opposite the windows and exhaust is usually effected through grilles in the bottom of the doors of the clothes closets, from which the exhaust ducts lead to exhaust fans in pent houses on the roof (Seymour and Danforth) or directly to roof ventilators (Salem Hyde, Fig. 1).

Thermostatic control systems for regulating the admission of steam to the direct

FIG. 2. MERRICK SCHOOL, SYRACUSE, N. Y.

and to the indirect radiators have been installed and are operated in these schools. Corridors of these schools have recirculating grilles connected with the fresh air supply shaft.

The naturally ventilated schools are of wooden interior construction; the newest of the three was built 40 years ago, the oldest is more than 50 years old. The buildings have but four, five or six rooms on a floor and with most rooms at corners of the buildings, daylight generally comes from two sides. For heating and ventilation, fresh air is taken from the outside at grade and is passed over warm (or hot) air furnaces or partially by-passed around them. It is then delivered to the rooms through masonry flues leading to registers which in the rooms of one school (Merrick, Fig. 2) are located in the inside wall at the floor, and in the others (Montgomery and Townsend) 8 to 10 ft. above the floor. The former building, which has an old Smead plant, has multiple vents in the base-boards of the outside walls, the spaces between the floor joists serving as ducts which convey the air back to the interior partitions. These partitions are hollow and the air passes down in these hollow spaces and eventually reaches basement ducts which lead it to the bottoms

City_____ School month

School_____ From_____ 192____

Room No._____ to_____ 192____

Grade_____ Teacher_____

TEMPERATURE RECORD

DAY OF WEEK	MONTH	HOURS OF OBSERVATIONS											COMPUTATIONS		REMARKS Note inclement Weather conditions here
		OUTDOOR			INDOOR										
					A.M.				P.M.						
		1	2	3	1	2	3	4	1	2	3	4	SUM.	AVE.	
Monday															
Tuesday															
Wednesday															
Thursday															
Friday															
SUM															
AVERAGE															
Monday															
Tuesday															
Wednesday															
Thursday															
Friday															
SUM															
AVERAGE															
Monday															
Tuesday															
Wednesday															
Thursday															
Friday															
SUM															
AVERAGE															
Monday															
Tuesday															
Wednesday															
Thursday															
Friday															
SUM															
AVERAGE															

INSTRUCTIONS CONCERNING THE TEMPERATURE RECORD

The temperature record provides spaces for 3 outdoor and 8 indoor readings daily. Outdoor readings are to be made at a carefully selected spot 5 minutes before the opening of each session and at the end of the afternoon session. (On one-session days, in order to have two readings, the second may be taken at the end of the session.)

Indoor readings are requested at *each session*, as follows:

1. When the session opens.
2. Immediately before the mid-session recess or exercise period.
3. Immediately after the mid-session recess.
4. Just before the session ends.

The number at the head of each column corresponds to the time of observation given in the above list. If, because of an oversight or for any other reason, a reading happens to be omitted, mark a cross (X) in the space where the reading should have been recorded. In any case, never record an estimate of what the reading might have been.

FIG. 3. FORM FOR RECORDING ROOM TEMPERATURES

of large and lofty chimneys. These chimneys have stoves for warming the rising column of air to insure a lively draft. In the other two buildings, gravity exhaust ducts taken from the floor or at floor level in the interior partitions lead to the base-

ments, where trunk ducts connect with similar large masonry ventilating chimneys. In the Townsend school, the metal chimney for smoke from the furnaces rises in the center of the brick ventilating chimney. The provision for temperature control is entirely manual and consists of regulating the amount of warm air entering the room by adjusting the inlet damper. Closing off the warm air with this damper opens at the same time a direct cold air by-pass. To avoid overheating, windows are opened frequently. There is, obviously, no air washing in these schools and equipment for the artificial introduction of moisture is lacking. The wooden air ducts in these old buildings are, of course, contrary to all modern requirements for school building construction.

It might be pointed out that these naturally ventilated schools were not ventilated by the window-gravity method recommended by the Commission and it should be said that no money was spent to alter any building or its heating or ventilating equipment for this study or to improve the methods of operation. Further, no instructions were issued or suggestions made as to how any of the systems might be operated to produce better results.

Organization of the Study

In the absence of automatic temperature-recording instruments, it was planned to have the teachers record the dry-bulb temperatures, as shown by the classroom thermometers, four times each session (eight times daily) on forms provided by the Commission, Fig. 3. In one school (Seymour) temperatures were recorded six times per session, or twelve times daily. Subsequent analysis of these data showed that although the averages of the 12 daily readings were in fair agreement with the averages of the 8 readings made at hours that were routine in the other schools in the study, the averages of the four additional readings taken in this school varied considerably from the average of the greater number of readings. This indicated that eight readings per day was just as satisfactory as twelve and more reliable than four and, for that reason, eight temperature readings per day has become the standard procedure in the studies.

In addition to the temperature records, the teachers were requested to keep an attendance and health record (Fig. 4) on which they recorded for each session:

a. The pupils on the active roll
b. The pupils present
c. The pupils present with respiratory illness
d. The pupils absent
e. The pupils absent with respiratory illness.

On this form, the following instructions were given:

1. For the purpose of this study the pupils enrolled are to be continued on the active roll, regardless of the length of absence, unless the family moves from the school district or the pupil leaves school permanently, and

2. This term (respiratory illness) includes—coryza, pharyngitis, tonsillitis, laryngitis, bronchitis, pneumonia, tuberculosis, grippe, etc.

This first rule was adopted to eliminate from the study the effects of the practice of dropping from the active roll all pupils absent more than three days. The second

City _____ School month
Ward _____ From _____ 192__ to _____ 192__
School No. _____ Pupils enrolled to date _____
Room No. _____ Teacher _____

ATTENDANCE AND HEALTH RECORD

DAY OF WEEK	DATE	SESSIONS	PUPILS ON (active) ROLL(1)	PUPILS PRESENT		PUPILS ABSENT		REMARKS
	MONTH			TOTAL	With (2) Respiratory Disease	TOTAL	With (2) Respiratory Disease	Indicate holidays, vacation days, unusual weather conditions, etc.; also any change of pupils on roll.
Monday		A.M.						
		P.M.						
Tuesday		A.M.						
		P.M.						
Wednesday		A.M.						
		P.M.						
Thursday		A.M.						
		P.M.						
Friday		A.M.						
		P.M.						
Monday		A.M.						
		P.M.						
Tuesday		A.M.						
		P.M.						
Wednesday		A.M.						
		P.M.						
Thursday		A.M.						
		P.M.						
Friday		A.M.						
		P.M.						
Monday		A.M.						
		P.M.						
Tuesday		A.M.						
		P.M.						
Wednesday		A.M.						
		P.M.						
Thursday		A.M.						
		P.M.						
Friday		A.M.						
		P.M.						
Monday		A.M.						
		P.M.						
Tuesday		A.M.						
		P.M.						
Wednesday		A.M.						
		P.M.						
Thursday		A.M.						
		P.M.						
Friday		A.M.						
		P.M.						
TOTAL								
Rate per 1,000								

FIG. 4. TEACHERS ATTENDANCE AND HEALTH RECORD

rule listed for the benefit of physicians and nurses the terms included under the heading "respiratory illness."

During the school year 1926–27, it was not possible to provide sufficient medical or nursing service to have respiratory illnesses determined by either of these agencies, and diagnosis, if such it can be called, of illness among the pupils present became the responsibility of the teachers. In practice, the term "respiratory illness" and the medical diagnoses included under that term, were interpreted under the more common headings: cold and sore throat.

No specific instructions were issued on this point, but it had been expected that

the teachers would depend on the nurses, whenever they were available, to aid them in deciding whether a child was or was not affected with respiratory illness. In time, this became the usual but not the universal practice. The teachers retained the ultimate responsibility for diagnosis, and although the personal equation enters largely, there is no reason to suspect that the averages of teachers' opinions on respiratory illness among pupils present would favor one type of ventilation over another.

Further, the writer attaches more importance to absenteeism and its causes than to diagnoses of respiratory illness among the pupils present made by the teacher. Absence from school is a definite matter and, with reasonable follow-up, the cause of absence can be determined with a fair degree of accuracy. The Syracuse De-

TABLE 2. SUMMARIZED ATTENDANCE AND HEALTH RECORDS

According to Type of Ventilation

Item	Attendance and Health Records	Schools with Steam Heat, Automatic Temp. Control, Mechanical Ventilation	Schools with Hot Furnace Heat, Manual Temp. Control, Natural Ventilation	Excesses in Mechanically Ventilated Schools
A	Total pupil sessions	228,454	137,596	
B	Total absences	16,413	6,768	
	Per cent of total pupil sessions	7.2	4.9	47%
C	Absences due to respiratory diseases	6,820	2,500	
	Per cent of total pupil sessions	3.0	1.8	67%
	Per cent of total absences	41	37	11%
D	Pupil sessions attended	212,041	130,828	
	Per cent of total pupil sessions	92.8	95.1	
E	Respiratory illness among pupils present	28,717	9,658	
	Per cent of total pupil sessions	12.6	7.0	80%
	Per cent of pupil sessions attended	13.6	7.4	84%
F	Respiratory illness among pupils present and absent	35,537	12,158	
	Per cent of toal pupil sessions	15.6	8.8	77%
G	Mean temperatures (° F.)	70.0	68.5	1.5
H	Average age of pupils: years	10.3	9.1	1.2
I	Percentage pupils of American parentage	72.7	54.6	33
J	Number of pupils	1,232	794	

partment of Education has a highly developed service for checking up the cause of absenteeism by the school nurses and truant officers.

The cause of every absence is reported by the parent and is subject to confirmation by the truant officer or nurse. This must not be taken to mean that every absence is investigated by these officials, but it does mean that the cause of absence will be reported well within the limits of accuracy of other factors against which it will be tested. Further, there is no reason to suspect that this method of determining absenteeism by cause would react for or against any type of ventilation.

As will be seen, the distribution of age, sex and race stock of the various school populations is such as to offset any special activity of nurses and truant officers in certain parts of the city or among any special groups of the general population.

It was originally intended to have a competent, trained person giving his entire time to the making of supplementary observations of the air conditions in the class-

rooms. These observations would include the physical tests necessary for the determination of:

a. Relative humidity
b. Air change
c. Air motion
d. Dust
e. Carbon dioxide.

The right person for this post was not found and ultimately the Commission's research engineer from Cataraugus County and the writer made one round of the classrooms to check the accuracy of the room thermometers, to determine the corrections that must be applied to the recorded temperatures and to get some idea of the heat distribution and the relative humidities.

The pupil session has been taken as the unit of measurement; the absence of

TABLE 3. ATTENDANCE AND HEALTH RECORDS

In Mechanically Ventilated Schools

Item	Attendance and Health Records	SCHOOLS Included in Study Salem Hyde	Seymour	Danforth	Total
A	Total pupil sessions	33,105	126,464	68,885	228,454
B	Total absences	2,116	9,704	4,593	16,413
	Per cent of total pupil sessions	6.4	7.7	6.7	7.2
C	Absences due to respiratory illness	1,128	3,249	2,443	6,820
	Per cent of total pupil sessions	3.4	2.6	3.5	3.0
	Per cent of total absences	53	33	53	41
D	Pupil sessions attended	30,989	116,760	64,292	212,041
	Per cent of total pupil sessions	93.6	92.3	93.3	92.8
E	Respiratory illness among pupils present	6,765	17,189	4,763	28,717
	Per cent of total pupil sessions	20.4	13.6	6.9	12.6
	Per cent of pupil sessions attended	21.8	14.7	7.4	13.6
F	Respiratory illness among pupils present and absent	7,893	20,438	7,206	35,537
	Per cent of total pupil sessions	23.8	16.2	10.4	15.6
G	Mean temperatures (° F.)	70.2	70.1	69.5	70.0
H	Average age of pupils: years	8.3	11.1	9.5	10.3
I	Percentage pupils of American parentage	91.8	62.0	85.5	72.7
J	Number of pupils	146	707	379	1,232

ten pupils for a single session is counted the same as the absence of one pupil for a school week of ten sessions, and so on.

Enough has been told in these two sections to show that while the study was of a purely preliminary nature, and, therefore, must not be clothed with more reliability than the methods warrant, the data have been collected with a care that will at least recommend their examination and the tentative acceptance of any outstanding significant results as indications of phases of the problem requiring further study.

Gross Results

The gross or crude results of the study are shown in Table 2.

It will be seen that the study covered some 366,000 pupil sessions; that the

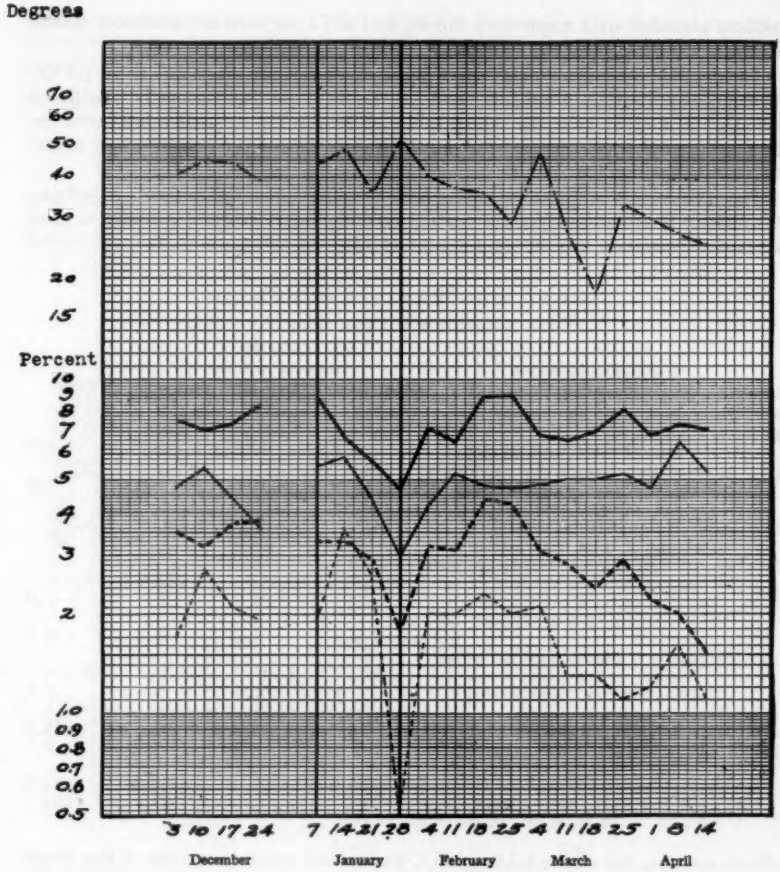


FIG. 5. TEMPERATURE DIFFERENCE (1) ABSENTEEISM (2) IN MECHANICALLY AND NATURALLY VENTILATED SCHOOLS AND RESPIRATORY ILLNESS ABSENTEEISM (3) IN MECHANICALLY AND NATURALLY VENTILATED SCHOOLS BY WEEKS

mechanically ventilated schools showed excesses of 47 per cent in total absenteeism, 67 per cent in absenteeism due to respiratory illness, of 80 per cent in the pupil

sessions attended with respiratory illness, and of 77 per cent in respiratory illness among the pupils present and absent.

The detailed records on which these figures are based are given in Table 3 for the mechanically ventilated schools, and in Table 4 for the naturally ventilated schools. For ready reference, these tables show also the mean temperatures, the total number of pupils, the average ages of the pupils and the percentage of pupils of American parentage.

The incidence of respiratory illness, which was taken as the criterion in judging the relative merits of the types of ventilation under consideration, is known to have a seasonal variation and in the attempt to discover the cause of the differential

TABLE 4. ATTENDANCE AND HEALTH RECORDS

In Naturally Ventilated Schools

Item	Attendance and Health Records	SCHOOLS Included in Study Montgomery	Merrick	Townsend	Totals
A	Total pupil sessions	54,346	41,079	42,171	137,596
B	Total absences	3,523	1,669	1,576	6,768
	Per cent of total pupil sessions	6.5	4.1	3.7	4.9
C	Absences due to respiratory illness	1,089	977	434	2,500
	Per cent of total pupil sessions	2.0	2.4	1.0	1.8
	Per cent of total absences	31	59	28	37
D	Pupil sessions attended	50,823	39,410	40,595	130,828
	Per cent of total pupil sessions	93.5	95.9	96.3	95.1
E	Respiratory illness among pupils present	4,956	2,448	2,254	9,658
	Per cent of total pupil sessions	9.1	6.0	5.4	7.0
	Per cent of pupil sessions attended	9.8	6.2	5.6	7.4
F	Respiratory illness among pupils present and absent	6,045	3,425	2,688	12,158
	Per cent of total pupil sessions	11.1	8.4	6.4	8.8
G	Mean temperatures (° F.)	71.7	68.3	65.8	68.5
H	Average age of pupils: years	9.9	8.9	8.2	9.1
I	Percentage pupils of American parentage	65.0	91.4	4.6	54.6
J	Number of pupils	325	232	237	794

effects noted in the above tables, daily, weekly and monthly records of this study were correlated with the outdoor weather data based on the observations of the Syracuse Station of the United States Weather Bureau. The daily records of individual schools contained such wide variations as to give little suggestion of the cause-and-effect relationship; the monthly summaries were similarly lacking in information. However, the consolidated weekly data for the schools, grouped according to type of ventilation, when considered with the weekly weather summaries present a matter that is considered of sufficient importance for special mention here.

For the purpose of simplification, these data are presented graphically in two charts. Fig. 5 shows the curves of total and respiratory illness absenteeism in the two types of schools, together with an outdoor day-time temperature curve in-

verted by the simple process of subtracting the Monday-to-Friday mean temperatures at 8 A.M., noon, and 4 P.M. from 70 deg., which is sufficiently close to the indoor temperature of the schools as to make this inverted temperature curve

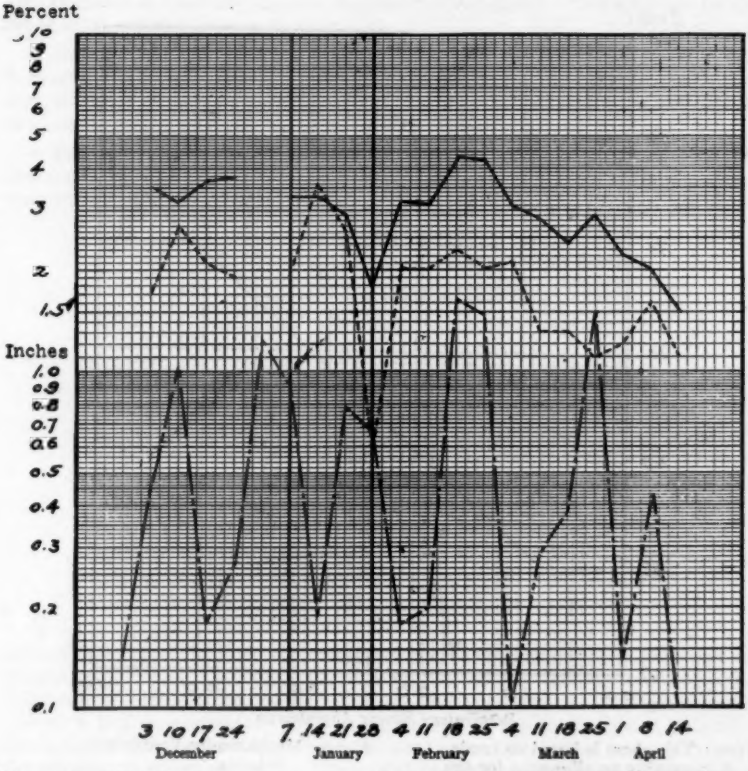


FIG. 6. RESPIRATORY ILLNESS ABSENTEEISM IN MECHANICALLY AND NATURALLY VENTILATED SCHOOLS (1) AND PRECIPITATION (2) BY WEEKS

reflect at the same time the difference between the indoor and the outdoor temperature.

Before embarking on any detailed discussion of the curves or their relationships, certain facts concerning the study and the school routine should be mentioned.

First, the study started November 29, and was, therefore, in operation but four weeks before it was interrupted by the Christmas holidays. The teachers' report that absenteeism is generally greater after holidays is supported by the attendance

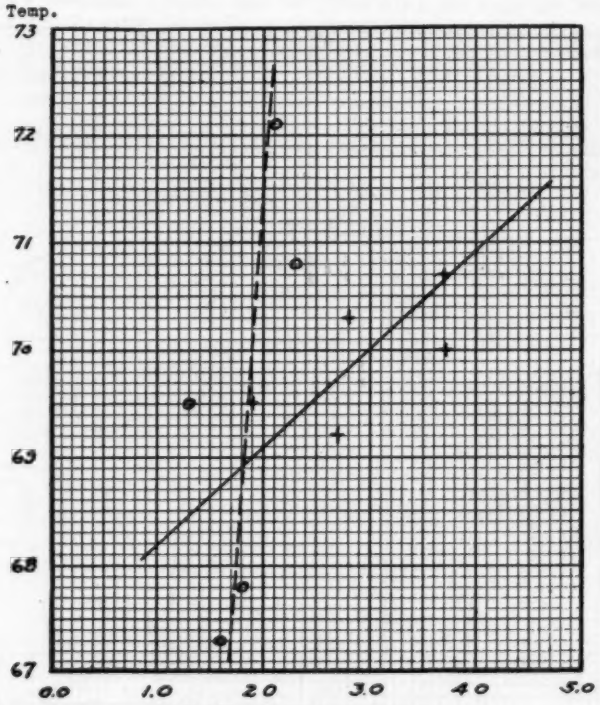


FIG. 7. MEAN TEMPERATURES AND AVERAGE RESPIRATORY ILLNESS ABSENTEEISM BY GRADES*

records, but that portion of it due to respiratory illness does not appear to be much greater after the holidays than before. Second, the week ending January 21 was the week of the Regent's examinations, certain lower grade classes being excused, others operating under unusual conditions with the result that total absenteeism

* Per cent of total pupil sessions.

and respiratory illness absenteeism in all schools is reduced in this week. Third, the week ending January 28 is the first week of the new term, when pupils who ultimately joined the classes, but who were absent for respiratory illness or other cause are not shown as absentees because they had not registered. This accounts for the dip in all the absence curves for that week.

If the first month of the study is discarded as a trial period and the next month because of the irregularities mentioned, the only valid portion of the curves is that from the week of February 4 to the end of the study—April 14—and the discussion of these charts will be restricted to this eleven-week period.

A glance at Fig. 5 will show that, although the total absenteeism in the mechanically ventilated schools (the second curve from the top) is uniformly higher than in schools with natural ventilation (Curve 3), neither of these curves shows

TABLE 5. SUMMARY OF CERTAIN FINDINGS FOR SIX SCHOOLS

School	Pupils of American Parentage Per Cent	Total Absenteeism*	Respiratory Illness Absenteeism*	Ratio R. I. Abs. to Total Per Cent	Pupils Present with Resp. Ill.*
		Mechanically Ventilated			
Salem Hyde	91.8	6.4	3.4	53	21.8
Seymour	62.0	7.7	2.6	33	14.8
Danforth	85.5	6.7	3.5	53	7.4
Total	72.7	7.2	3.0	41	13.6
		Naturally Ventilated			
Montgomery	65.0	6.5	2.0	31	9.1
Merrick	91.4	4.1	2.4	59	6.0
Townsend	4.6	3.7	1.0	28	5.4
Total	54.6	4.9	1.8	37	7.0

* Per cent of total pupil sessions.

any resemblance to the inverted temperature curve (at the top), suggesting that, in general, attendance is not adversely affected by outdoor temperature, or by the difference of temperature between indoors and outdoors. On the other hand, Curves 4 and 5—respiratory illness absenteeism in mechanically and naturally ventilated schools, respectively—have the same general downward trend as Curve 1 but apparently this is simply the effect of the well recognized seasonal prevalence of respiratory illness. Detailed comparison of the weekly trends of the curves shows so many instances of directly contradictory tendencies as to suggest that aside from their mutual relationship to the seasonal prevalence of respiratory illness, they have little in common. Before passing to the discussion of Fig. 6, attention is directed to the parallelism between Curves 2 and 4, which indicates that respiratory illness is a very important cause of absenteeism in mechanically ventilated schools. The relationship between Curves 3 and 5 is by no means so striking.

In Fig. 6 is presented what may turn out to be the outstanding finding of the study. The lower curve of this chart is the weekly precipitation—rain and melted snow—while the upper curves are the rates of respiratory illness absenteeism in the

mechanically and naturally ventilated schools. Again confining discussion to that period from February 4 to April 14, a marked similarity is noticed in the peaks of the upper and the lower curves. In other words, there appears to be a relationship between precipitation and respiratory illness absenteeism in the mechanically ventilated schools, which relationship does not appear to hold at all for the naturally ventilated schools.

Is there any reason or explanation for this differential effect? The mean temperature of the mechanically ventilated schools was 70.0 deg. fahr., while that of the naturally ventilated schools was 68.5 deg. fahr.

The conclusion that respiratory illness among the pupils is solely a direct function of the indoor temperature is not warranted in view of the fact that the naturally ventilated Montgomery School, in spite of the highest average temperature (71.7 deg. fahr.) of the six schools included in the study showed the second lowest respiratory illness absenteeism (2.0 per cent). This contention is further supported by

TABLE 6. RATIO OF RESPIRATORY ILLNESS ABSENTEEISM

Total Respiratory Illness (*i. e.*, among Pupils Present and Absent)

School	Percentage of Pupils of American Parentage	Pupils with Respiratory Illness		Ratio R. I. Abs. to Total R. I. × 100
		Total	Absent	
	Mechanically Ventilated			
Salem Hyde	91.8	23.8	3.4	14.3
Seymour	62.0	16.2	2.6	16.0
Danforth	85.5	10.4	3.5	33.7
Total	72.7	15.6	3.0	19.2
	Naturally Ventilated			
Montgomery	65.0	11.1	2.0	18.0
Merrick	91.4	8.4	2.4	28.6
Townsend	4.6	6.4	1.0	15.6
Total	54.6	8.8	1.8	20.5

Note: For every 100 pupil sessions of respiratory illness, there were due to that cause in Salem Hyde School 14 absences; in Seymour 16; in Danforth 33: etc.

Fig. 7, which shows the curves of average respiratory illness absenteeism correlated with average room temperatures by grades for the two types of ventilation.

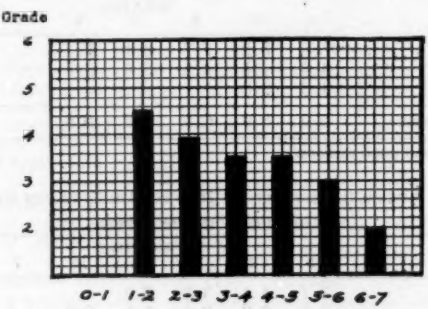
These curves are based on the crude data from the six schools, and do not take age and race stock into consideration, but their slope indicates that while, for each type of ventilation, higher temperatures are generally associated with higher rates of respiratory illness absenteeism, the difference of slope indicates that there is some other unfavorable agency at work in the mechanically ventilated schools.

From the single series of observations for relative humidity, there appeared to be no significant difference in the moisture content of the air in the two types of schools. The air and floor space per pupil are not significantly different. There remains the matter of air change and air motion.

It is possible that the higher rate of air change in the mechanically ventilated

rooms, which is assumed in the absence of data on that point, causes such rapid evaporation of the moisture in the shoes and clothing of the pupils in these schools as to chill them, perhaps insensibly, due to the absorption of their body heat as the water changes from liquid to vapor, and that in consequence of this chilling, respiratory diseases develop from the organisms generally present in the noses and throats of the pupils during the winter season.

This finding suggests that mechanical systems of ventilation should provide lower quantities and lower velocities of air in classrooms, and that there should be special provision, particularly in mechanically ventilated schools, for the drying



Respiratory Illness Absenteeism Rate Group
Per Cent of Total Pupil Sessions

Note:

In Grades 2–6 of Seymour, Danforth, Montgomery and Merrick Schools.
Average of grade numbers of rooms (a rough index of age) falling in the Respiratory Illness Absenteeism Rate Group.

FIG. 8. RESPIRATORY ILLNESS ABSENTEEISM ACCORDING TO SCHOOL GRADE (AGE) OF PUPILS

and warming of the feet of the pupils in stormy weather. So much for the indications of the gross results!

Does a critical examination of the data from the individual schools shed any further light on these findings?

A comparison of ratios given in Column 5 of Table 5 with the percentage of pupils of American parentage in Column 2, shows that in schools having a high percentage of pupils of American parentage, the effect of respiratory illness on the total absenteeism is much more pronounced than in schools where the population contains a higher percentage of pupils of foreign parentage. The conclusion that American born parents would keep their children home more readily because of a slight disturbance, whereas the foreign born parent would send the child on to school is not supported by the relative attendance of pupils with respiratory illness at the Salem Hyde School. However, if this school from which an unusually high incidence of respiratory illness was reported among the pupils present, were omitted from con-

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TABLE 7. AVERAGE ABSENTEEISM BY GRADES*

Mechanically Ventilated Schools

School	GRADES 2	3	4	5	6	7	8	School Average
Salem Hyde	8.3	7.3	5.9	5.1	...	...	...	6.4
Seymour	9.1	8.4	6.2	5.5	6.6	8.6	9.3	7.7
Danforth	7.1	8.7	6.9	5.8	5.1	...	...	6.7
Grade averages	8.3	8.3	6.3	5.5	6.0	8.6	9.3	7.2

Naturally Ventilated Schools

School	GRADES 2	3	4	5	6	7	8	School Average
Montgomery	5.8	5.2	7.7	6.1	7.1	...	...	6.5
Merrick	4.8	4.5	4.1	3.6	3.0	...	...	4.0
Townsend	4.6	2.8	...	...	...	...	...	3.7
Grade averages	5.0	3.9	6.5	4.6	5.8	...	...	4.9

* Per cent of total pupil sessions.

TABLE 8. AVERAGE RESPIRATORY ILLNESS ABSENTEEISM BY GRADES*

Mechanically Ventilated Schools

School	GRADES 2	3	4	5	6	7	8	School Average
Salem Hyde	3.7	4.1	3.3	2.9	...	...	...	3.4
Seymour	2.8	2.8	2.4	1.8	2.3	1.8	3.8	2.6
Danforth	5.2	5.1	2.9	3.5	1.4	...	...	3.6
Grade averages	3.7	3.7	2.8	2.7	1.9	1.8	3.8	3.0

Naturally Ventilated Schools

School	GRADES 2	3	4	5	6	7	8	School Average
Montgomery	2.0	1.5	2.0	1.4	2.6	...	...	2.0
Merrick	2.4	3.3	2.3	1.2	1.8	...	...	2.4
Townsend	1.1	0.9	...	...	...	...	...	1.0
Grade averages	1.6	1.7	2.1	1.3	2.3	...	...	1.8

* Per cent of total pupil sessions.

sideration, the tendency of American parents in this regard appears to be to keep ailing children home. This point is brought out in Table 6.

This comparison clearly indicates that race-stock and respiratory illness absenteeism are related and that, *as a consequence, one is not justified in a deduction of the relative merits of different types of ventilation on respiratory illness absenteeism unless the racial composition of the populations of the different groups is practically identical.*

The effect of the age distribution of the pupils is likewise important as is brought out in Table 7.

The progressive decrease in absenteeism with the advance in grade is most strik-

TABLE 9. SUMMARIZED ATTENDANCE AND HEALTH RECORDS

According to Type of Ventilation with Room Temperatures, Age and Nationality of Pupils Balanced

	Attendance and Health Records	Mechanically Ventilated Schools	Naturally Ventilated Schools	Excesses in Mechanically Ventilated Schools
A	Total pupil sessions	166,245	95,425	
B	Total absences	11,687	5,192	
	Per cent of total pupil sessions	7.0	5.4	29%
C	Absences due to respiratory illness	4,845	2,066	
	Per cent of total pupil sessions	2.9	2.2	32%
	Per cent of total absences	41	40	
D	Pupil sessions attended	154,558	90,233	
	Per cent of total pupil sessions	93.0	94.6	
E	Respiratory illness among pupils present	14,545	7,404	
	Per cent of total pupil sessions	8.8	7.8	13%
	Per cent of pupil sessions attended	9.4	8.2	14%
F	Respiratory illness among pupils present and absent	19,390	9,470	
	Per cent of total pupil sessions	11.7	10.0	17%
G	Mean temperatures (° F.)	70.0	70.3	
H	Average age of pupils' years	10.0	9.5	
I	Percentage of children of American parentage	71.0	76.0	
J	Number of pupils	1,086	557	

TABLE 10. ATTENDANCE AND HEALTH RECORDS

Two Mechanically Ventilated Schools

	Attendance and Health Records	SCHOOLS Seymour	Danforth	Totals
A	Total pupil sessions	97,360	68,885	166,245
B	Total absences	7,094	4,593	11,687
	Per cent of total pupil sessions	7.4	6.7	7.0
C	Absences due to respiratory illness	2,402	2,443	4,845
	Per cent of total pupil sessions	2.5	3.5	2.9
	Per cent of total absences	34	53	41
D	Pupil sessions attended	90,266	64,292	154,558
	Per cent of total pupil sessions	92.6	93.3	93.0
E	Respiratory illness among pupils present	9,782	4,763	14,545
	Per cent of total pupil sessions	10.0	6.9	8.8
	Per cent of pupil sessions attended	10.8	7.4	9.4
F	Respiratory illness among pupils present and absent	12,184	7,206	19,390
	Per cent of total pupil sessions	12.5	10.4	11.7
G	Mean temperatures (° F.)	70.2	69.5	70.0
H	Average age of pupils' years	10.2	9.5	10.0
I	Percentage of children of American parentage	60.0	85.5	71.0
J	Number of pupils	707	379	1,086

ingly illustrated in the schools with the more homogeneous populations: Salem Hyde, Danforth, Merrick and Townsend. In Seymour and Montgomery, after

TABLE 11. ATTENDANCE AND HEALTH RECORDS
Two Naturally Ventilated Schools

	Attendance and Health Records	SCHOOLS Montgomery	Merrick	Totals
A	Total pupil sessions	54,346	41,079	95,425
B	Total absences	3,523	1,669	5,192
	Per cent of total pupil sessions	6.5	4.1	5.4
C	Absences due to respiratory illness	1,089	977	2,066
	Per cent of total pupil sessions	2.0	2.4	2.2
	Per cent of total absences	31	59	40
D	Pupil sessions attended	50,823	39,410	90,233
	Per cent of total pupil sessions	93.5	95.9	94.6
E	Respiratory illness among pupils present	4,956	2,448	7,404
	Per cent of total pupil sessions	9.1	6.0	7.8
	Per cent of pupil sessions attended	9.8	6.2	8.2
F	Respiratory illness among pupils present and absent	6,045	3,425	9,470
	Per cent of total pupil sessions	11.1	8.4	9.9
G	Mean temperatures (° F.)	71.7	68.3	70.3
H	Average of pupils' years	9.9	8.9	9.5
I	Percentage of children of American parentage	65.0	91.4	76.0
J	Number of pupils	325	232	557

TABLE 12. RESPIRATORY ILLNESS ABSENTEEISM AND MEAN TEMPERATURES OF CLASSROOMS, SHOWING GRADE, TYPE OF VENTILATION AND NATIONALITY OF PARENTS OF PUPILS

Mean Temp. (° F.)	Respiratory Illness Absenteeism Rate Group							No. of Rooms
	0–1	1–2	2–3	3–4	4–5	5–6	6–7	
75		N4F						1
74								0
73		N5F						1
72			M4A					1
71		N3F N6F	M2F N2F M6F	M3F				6
70		M5F N2F M6F N3F	M2F N4A M4F N4F M4F	M2F N6F	M2A	M3A	M2A	14
69		M3F N6A M3F	M4F M5F M5A M6F	M4A		M3F M3A		10
68		M6A	N2A	N3A				3
67				N3A	M5A			2
66		M6A N5A						2
No. of rooms	..	14	14	6	2	3	1	40
Average grade no.	..	4.5	3.9	3.5	3.5	3.0	2.0	..
Type of ventilation	..	6M 8N	10M 4N	3M 3N	2M ...	3M ...	1M ...	40
Race-stock	..	10F 4A	10F 4A	3F 3A	... 2A	1F 2A	... 1A	40
Av. temp. (°F.)	..	70.3	70.3	69.7	68.8	69.7	70.7	..

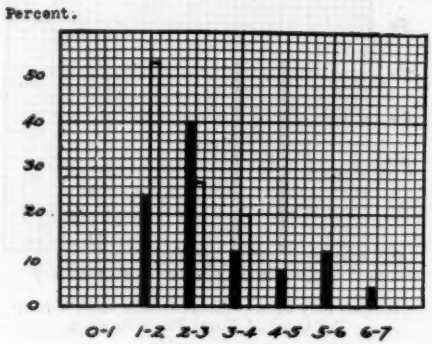
M—Mechanical Ventilation
N—Natural Ventilation
Numbers are Grade Numbers

A—High Percentage Pupils of American Parentage
F—High Percentage Pupils of Foreign Parentage

showing decreases in the early years, a definite up-turn is noted after the fourth or fifth grade. This indicates that the age distribution of the groups should also be approximately identical before any very reliable conclusions may be deduced, although Table 8 which presents the respiratory illness absenteeism by grades does not show the same relationship with grade as does total absenteeism.

Refined Results

The critical examination of the gross findings of the study was sufficiently indicative of precautions that must be observed in interpreting these findings as to warrant a recast of the data with due regard to these indications. This has been



Respiratory Illness Absenteeism Rate Group
Per Cent of Total Pupil Sessions

Mechanically Ventilated Schools
Naturally Ventilated Schools

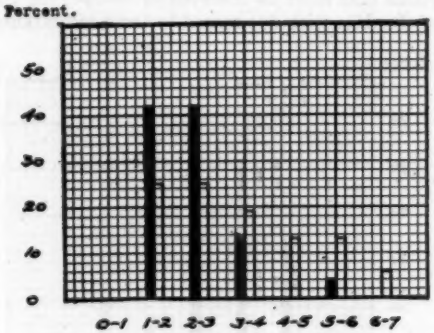
Note: Percentage of rooms in Grades 2–6 of Seymour, Danforth, Montgomery and Merrick Schools, having the indicated type of ventilation, falling in the Respiratory Illness Absenteeism Rate Group.
Differences in age, race-stock and mean temperatures are balanced.

FIG. 9. RESPIRATORY ILLNESS ABSENTEEISM ACCORDING TO TYPE OF VENTILATION

accomplished with the elimination of the Salem Hyde from the mechanically ventilated schools, and of Townsend from the naturally ventilated schools, and restricting consideration to grades 2 to 6 only. These schools were eliminated because Salem Hyde is located in quite a different section of the city from any of the other schools, and Townsend is attended by pupils of a different race-stock. Of the remaining four schools, two (Seymour, mechanical, and Montgomery, natural) are in the same general neighborhood and are attended by much the same type of pupil. The same observations hold true for Danforth, mechanical, and Merrick, natural. The findings of this treatment of the data together with the mean tem-

peratures, the average ages of the pupils, and the percentage of pupils of American parentage are presented in Tables 9, 10 and 11.

Although, as would have been expected with this refined treatment, the figures differ from those of the gross findings, and in spite of every remaining trace of influence of temperature, age and race in favor of the mechanically ventilated schools, the total absenteeism in these schools is 29 per cent higher and the respiratory illness absenteeism 32 per cent higher than in the naturally ventilated schools.



Respiratory Illness Absenteeism Rate Group
Per Cent of Total Pupil Sessions

High Foreign Parentage

High American Parentage

Note:

In Grades 2–6 of Seymour, Danforth, Montgomery and Merrick Schools.
Per cent of rooms in schools having the indicated distribution of pupils by nationality of parents, falling in the Respiratory Illness Absenteeism Rate Group.

FIG. 10. RESPIRATORY ILLNESS ABSENTEEISM AND RACE-STOCK

Restricting consideration to grades 2 to 6 (both inclusive) in these four schools, in order to balance the influence of the factors mentioned above, the frequency Table 12 has been derived from the original data.

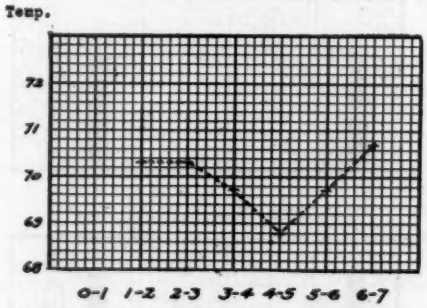
Figs. 8, 9, 10 and 11 have been prepared from Table 12.

Chart, Fig. 8, shows that regardless of differences of race and room temperature, respiratory illness absenteeism appears to be related to the school grade of the pupil (a rough index of age); the higher the grade (age), the lower the respiratory illness absenteeism.

Chart, Fig. 9, shows the percentage of rooms of the two types of ventilation under consideration falling in the indicated respiratory illness absenteeism rate groups. In naturally ventilated schools, 53 per cent of the rooms reported respiratory illness absenteeism rates between 1 per cent and 2 per cent, 27 per cent between 2 and 3,

and the remaining 20 per cent showed respiratory illness absenteeism rates less than 4 per cent. In the mechanically ventilated schools, only 24 per cent of the rooms had respiratory illness absenteeism rates from 1 per cent to 2 per cent, whereas 40 per cent of the rooms had rates between 2 per cent and 3 per cent and 12 per cent between 3 per cent and 4 per cent, etc.

Chart, Fig. 10, shows the relationship of race-stock to the respiratory illness absenteeism rate. The rooms attended by pupils among whom the percentage of foreign parentage is higher, show a decided tendency toward low rates of respiratory illness absenteeism. In Table 6, it was shown that the pupil of



Respiratory Illness Absenteeism Rate Group
Per Cent of Total Pupil Sessions

Note:

Mean temperatures of rooms in Grades 2–6 of Seymour, Danforth, Montgomery and Merrick Schools, falling in Respiratory Illness Absenteeism Rate Group.

FIG. 11. RESPIRATORY ILLNESS ABSENTEEISM AND MEAN TEMPERATURES

American parentage was more apt to be kept home if he showed signs of illness.

Chart, Fig. 11, shows the mean room temperatures corresponding to the various rates of respiratory illness absenteeism. With a greater number of rooms under observation, a different result might have been obtained, but the present study does not show any definite relationship between room temperature and respiratory illness absenteeism when the findings of all the rooms (in grades 2–6 of these four schools) are grouped and the factors of type of ventilation, age and race-stock are not considered.

These charts have been prepared to demonstrate the importance in a study of this nature of the age and race composition of the populations of the various schools. It would have been equally important to examine the effect of the sex distribution in the various schools, had this factor shown any marked variation.

Chart, Fig. 12, shows how the refined results compare with the crude findings of

the study and at the same time illustrates the superiority of the health effects of natural ventilation which this preliminary study indicates.

Conclusions

If our original data had been based on the more reliable foundation of diagnosis of respiratory illness by competent persons, and had our follow-up of absentees

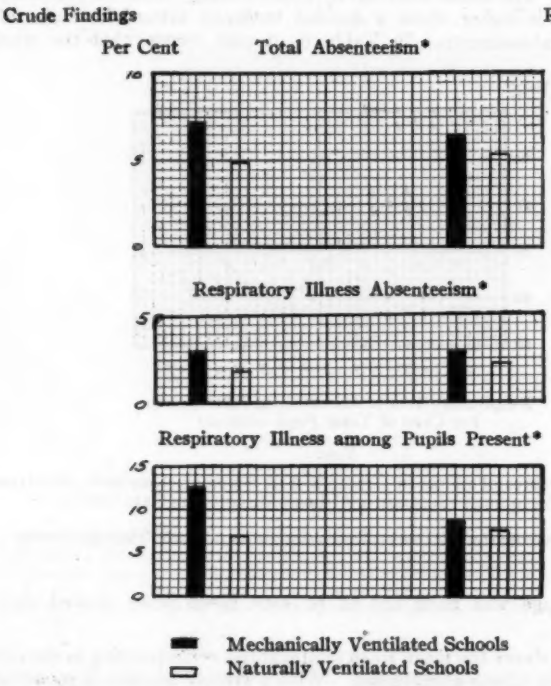


FIG. 12. ATTENDANCE AND HEALTH RECORDS IN MECHANICALLY AND NATURALLY VENTILATED SCHOOLS

been such as to preclude the possibility of falsification of cause of absence, and had the numbers of individuals included in our study been greater, we should be warranted in making the unqualified assertion of what this preliminary study strongly suggests, namely, that natural ventilation has some inherent virtue which mechanical ventilation does not possess, or that mechanical ventilation involves some harmful influence from which natural ventilation is free.

The high correlation between respiratory illness absenteeism in the mechanically

* Per cent of total pupil sessions.

ventilated schools and precipitation has been shown. For those interested in the mathematical relationship, it should be stated that with the seasonal trend of respiratory illness removed, the correlation ratio for the period February 4 to April 14 is $+0.82 \pm 10$, apparently both reliable and significant, whereas the corresponding figures for the naturally ventilated schools are $+0.35 \pm 0.27$, demonstrating no significant correlation.

It shall be our endeavor through further studies to remove the doubts that cloud the findings of this preliminary study and to demonstrate whether the high rate of air change is the causative agency in the excess of respiratory illness absenteeism in the mechanically ventilated schools.

DISCUSSION

PERRY WEST (WRITTEN): I feel that we are particularly fortunate in having Mr. Duffield present these data and conclusions of the New York State Commission on ventilation studies in the Syracuse Schools to us at this time for discussion.

In studying this report, I am greatly impressed with the intentions of fairness and with the extent to which the investigations and the analyses have been carried on in an honest endeavor to discover the underlying causes of whatever differences, if any, may exist between the effects of these different kinds of ventilation.

It seems to me that these data and the spirit in which they are presented together with their full and open discussion by the members of this Society should constitute a big step toward a better cooperation on undertakings of this character in the future.

This is the first time, to my knowledge, that in an analysis of this kind, it has been so definitely attempted to determine the influences of the seasons, the age of pupils, the race stock and the precipitation upon the absence and illness records due to respiratory diseases of the pupils.

I am also impressed with the way mean values have been worked out and used instead of averages and feel that there is much in the technical methods of analysis to be commended.

With all due respect to this great amount of data collected and to the great amount of work entailed in its analysis a careful study has convinced me that it would be improper to base any very definite conclusions upon this report. This, I believe, is also the general conclusion of the author, although in several places I believe that the conclusions suggested are not conclusively borne out by the data. Its chief value, I should say, lies in more clearly pointing the way to the attainment of more definite results in the future. In this respect it should more than prove the worth of the great amount of work involved and I, for one, should not wish to have anything which may be presented here in the way of constructive criticism, in any way construed as derogatory to the value of this paper.

I should like to state my reasons for these conclusions and to discuss them as we go along as follows:

First: That these studies, like all other such field studies of schoolhouse ventilation, are unfortunately based on the tests of different kinds of systems of ventilation instead of on the tests of different kinds of indoor schoolhouse atmospheric

conditions. In these tests more of the physical qualities of the indoor atmospheric conditions were recorded except the dry-bulb temperatures and these temperatures were only taken at one point in each room eight times per day.

This means that we know comparatively nothing about the comparative physical qualities of the atmosphere within the various schools from which to begin a study to determine the particular property or properties responsible for the different effects on the pupils.

In the analysis of the dry-bulb temperature effects the conclusions seem to be diametrically opposed to all former contentions of the New York State Commission on Ventilation, to the effect that overheating was the greatest cause of respiratory illness.

This may be due to the fact that the temperatures as taken do not reflect the time and space variations and also to the fact that in the analysis proper allowances are not made for the differences in race stock and age of pupils and for the differences in the sizes and arrangement of the buildings.

These are some of the reasons, in my judgment why Fig. 7 shows such an increase in the rate of respiratory illness absenteeism for the mechanically ventilated schools and comparatively no increase for the naturally ventilated schools in proportion to the increase in temperature.

There is still another and more important reason for the great difference in the slope of these two curves in Fig. 7. By referring to Table 3, item A, you will note that while the temperatures for the mechanically ventilated schools are more regular than those for the naturally ventilated schools, as shown in Table 3, item B, there is a consistent decrease of temperature with increase of the grades in the mechanically ventilated schools and just the reverse in the naturally ventilated schools.

By referring to Fig. 8 you will note that the rate of respiratory absenteeism decreases with the increase of the age of the pupils at the rate of about $1^1/_2$ per cent per grade.

It is easy to see, therefore, that the influence of the difference in grades was working in parallel with the influence of the difference in temperatures in the mechanically ventilated schools and directly opposed in the naturally ventilated schools.

It should also be pointed out that Fig. 7 is based on data in Table 8 which includes the data on the Salem Hyde and Townsend Schools (as given in Table 6) which schools were thrown out by the author in his final analysis on account of the wide differences in the race stock of the pupils in these two schools.

As a matter of fact this Fig. 7 should be recast from the detailed data on the four schools, not eliminated by their incomparable differences in rack stock, and by balancing the effects of grades. In this case it will be found that the two curves for respiratory absenteeism against dry-bulb temperatures will register about parallel not so far apart, conveying toward the zero rate of absenteeism between 67 deg. fahr. and 69 deg. fahr. and increasing at the average rate of about 1 per cent per degree of temperature increase.

The decrease in rate of absenteeism with increase in age will also be found to run more or less parallel when the influence of temperature differences is balanced.

With further reference to the matter of temperatures it will be noted that the mean values given for mechanically ventilated schools are more regular than those

given for the naturally ventilated schools. This is as would be expected on account of the former being automatically and the latter manually controlled.

It is reasonable to suppose that these manually controlled schools were operated as usual, *i. e.*, by getting up a good fire early in the morning, letting it die down toward noon, getting up another fire in the afternoon and letting it die down in the late afternoon. This may mean that the pupils in these schools were subjected to the maximum temperatures for comparatively short periods while those in the other schools were in about the same temperatures all the time It would be interesting in this connection to have the pupil hour degrees for all of the schools.

Second: There are so many variables consisting of different sizes and arrangement of buildings, race stock, age, sex and grade of pupils, temperatures, other physical properties of the indoor atmosphere, outside weather conditions, seasonal changes, precipitation, etc., many of which were not completely recorded, some not recorded at all and none of which were eliminated from any of the tests, that I do not see how any hard and fast conclusions can be drawn.

It is true that every attempt has been made to balance off many of these disturbing factors but this has of course been impossible for without knowing the relative weight of each there is no proper way of compensation.

The naturally ventilated buildings by having windows on two sides may get more sunlight which in turn may cause more vitality in the air or curtail the activity of the disease germs. These buildings by being smaller may be operated more like a small family with more attention to wet feet, proper clothing and other health precautions. The little red schoolhouse was a more healthful abode for our forefathers than is the modern school of today. It should be noted that there were about twice the number of pupils in the mechanically ventilated school as in the naturally ventilated ones.

There may be something in relative volumes of air and air motions, but without any data except the general assumption that these are greater for mechanically ventilated schools we haven't anything very definite to go on.

There may be something in the vitality of entering air which has not come into contact with heaters but there are no data on this except the statement that part of the air for the naturally ventilated schools is bypassed around the heaters. This is also probably true of the mechanically ventilated schools. There should be data on this and as to the relative amount of direct radiation in the mechanically ventilated schools and as to the temperature of the incoming air to classrooms.

There may be something in the temperature variations in the naturally ventilated schools but the data with only eight temperature readings per day at one point in each room would not throw much light on this.

Regardless of the fact that it is believed by some that the moisture contents of the air, the dust contents and the bacteria contents (within the ranges ordinarily found in classrooms) have no material bearing upon the results; we shall never know just what weight these factors exert without including them in such a study as this. In regard to the conclusions drawn regarding the incidence of respiratory absenteeism and precipitation it would seem to me that while interesting and very deserving of more study these are not borne out by even the curves in Fig. 6 as it will be noted that out of the ten-week period under consideration the trend of the

rate of respiratory absenteeism for mechanically ventilated schools followed the precipitation curve five weeks and the rate for the naturally ventilated schools followed it six weeks whereas the conclusions drawn are that the former follow the precipitation almost exactly and that there is little or no similarity for the latter. These precipitations and absenteeism curves may be misleading to some as they seem to be on a logarithmic scale.

The hypothesis drawn that the higher rate of air change and air motion in the mechanically ventilated schools chills the pupils by rapid evaporation from wet clothing and shoes on rainy days only shows that more physical data are needed.

Inasmuch as Figs. 8, 9, 10, 11 and 12 are all made up without any attempt to balance the other variable factors besides the one upon which each particular chart is based, it is very questionable as to what these would show with these variable factors eliminated.

In the final conclusions drawn from what is termed the refined data it is stated that Fig. 12 illustrates the superiority of the health effects of natural ventilation which the preliminary study indicates.

I think this should be interpreted in conjunction with the further statements regarding the author's qualifications for making any positive assertion of what the study is said to suggest, namely, that natural ventilation has some inherent virtues which mechanical ventilation does not possess, or that mechanical ventilation involves some harmful influences from which natural ventilation is free.

Third: It is unfortunate that here again we have all of this work and study done and interpreted by one interest whose intention, according to the origin and scope of this report, was to check and prove its own findings made in the New York City schools in 1913–17.

It would seem that the cooperation of the medical profession and scientists in allied fields might prove of more value in collaboration with such work than in the mere criticism after it is all done.

Here again I must say, as I have said many times before, that it does seem fundamentally wrong for the school, Health and Medical authorities to continue trying to decide the design of Heating and Ventilating equipment instead of trying to decide the kind of indoor conditions they require, while the Heating and Ventilating Engineer is forced to continue the research work of determining what is needed before he can design the proper apparatus to produce it.

I believe that these Syracuse studies will bear much good fruit and that they will at least go a long way toward determining what factors must be balanced or eliminated in order to secure dependable results.

The greatest light which it brings to me, however, is that this is an honest and conscientious endeavor to learn the truth and if the controversial idea of trying to test systems of ventilation could be eliminated and more cooperative work done among all of us along the lines of trying to find out just what there is in the atmospheric conditions that is most conducive to health and comfort, there would be little time lost in producing these conditions. I think a test set up for physiological reactions along the lines suggested by these studies parcelled with full data on the physical conditions of the indoor and outdoor atmospheres and without any idea of deciding from such tests alone the kind of apparatus best suited for schoolhouse work is the real solution for some very constructive cooperative work.

A. R. ACHESON (WRITTEN): I am sure we all appreciate the comprehensive data that Mr. Duffield has submitted regarding the absences of pupils in certain schools under tests in Syracuse. Anyone who has studied this question realizes the difficulty of securing reliable information.

This report and the earlier report of the Commission give some of the best available on this subject and I am sure considerable use will be made of this information.

When it comes to analyzing the results I find I cannot agree with Mr. Duffield's interpretation. I am inclined to believe he has been misled by averages.

The general procedure in scientific tests when trying to find the effect of a variable, is to keep other conditions as nearly constant as possible and vary the process which is being specifically considered and note the effect of this variation. If the variation is always in a certain direction one is justified in believing the effect is due to the variation. If, however, the variation is first in one direction and then in the other the engineer or scientist comes to the conclusion that some other variable is affecting the results. He thereupon proceeds to try and eliminate this variable and does not draw any conclusion as to the effect of the first variable until he gets the other variables eliminated.

In the report under consideration the absence data are compared for schools with two systems of ventilation and it is tacitly assumed that the difference in absences is due to the difference in ventilation systems. If the absences were always greater for one system than for another this might be a fair assumption if supported by sufficient tests. However, when results vary first in one direction and then in another, in other words, they cris-cross, it would seem to indicate that other variables are having an effect.

Of course, when one notices children are in school only a small proportion of the 24 hours and that they are subject to varying weather conditions, food conditions, home conditions, etc., one does not have to look far for probable causes for the variations.

As definite proof of the wide variation in absences due to the causes other than the ventilation system, I submit Table A.

TABLE A. ABSENCES DUE TO RESPIRATORY CAUSES, RATE PER 1000 PUPIL SESSION UNITS. COMPILED BY A. R. ACHESON

From N. Y. State Com. on Vent. Report, Pp. 605, 606, 429

School	Open Window Moderate Temp. Room	Absence Rate per 1000	Fan Room	Absence Rate per 1000
2 BX	301	10.7	207	22.4
	302	7.7	307	13.2
	316	11.6	310	1.3
P. S. 97	302	6.4	303	2.3
	313	7.1	308	2.7
	501	3.0	502	6.8
P. S. 115	312	23.3	308	44.0
	502	40.2	311	50.4
	503	29.8	...	...
Average of above schools plus several others		10.5	...	13.4

The data given in Table A are taken from the Ventilation Report of the New York State Commission on Ventilation and show the extreme variability of the data on Respiratory absences for different rooms in the same school even with the same ventilation system. The variation within a system is greatly in excess of the average difference between systems and so the data indicate that causes other than differences in ventilation systems are having a predominant effect. The ranges in the above data are from 3.0 to 40.2 for gravity systems and from 1.3 to 50.4 for fan systems, whereas the averages for the above (plus certain other schools) are 10.5 for gravity systems and 13.4 for fan systems.

As further evidence I would also submit Table B, as follows:

TABLE B. TOTAL ABSENCES IN CERTAIN SCHOOLS, ELMIRA, N. Y., EXPRESSED IN PERCENTAGES OF AGGREGATE ATTENDANCE, COMPILED BY A. R. ACHESON

School	1924–25	1925–26	1926–27	
No. 2 Grade	8.5	9.4*	8.5*	Gravity Furnace 1924–25 Changed to central fan 1925–26
No. 7 Grade	6.7	8.7	5.4	
No. 8 Grade	6.9	9.5	6.2*	Gravity Furnace 1924–26 Changed to central fan 1926–27
No. 9 Grade	7.9	9.0	9.0	
No. 11 Grade	6.1	8.2	6.0*	Gravity Furnace 1924–26 Changed to central fan 1926–27
So. Side High-Grade Dept.	6.5*	5.2*	4.1*	Central Fan

In the grade schools proper the figures indicated by (*) show where furnaces were removed and central fan systems installed.

These data apparently indicate a marked improvement by changing from gravity to fan operation. However, note the variable data for No. 7 School, which was not changed at that time. Note also the data for the grade department of the South Side High, which are the lowest averages but vary approximately 50 per cent. The variations are probably due to causes other than differences in ventilation systems.

The data given in Table B indicate that it is misleading to draw conclusions regarding the causes of absences from data drawn from a few schools taken over a few years.

The New York State Commission on Ventilation Report, page 432 states:

> In the analysis immediately following we have used chiefly the absence rates from respiratory illness, as they are believed to be more dependable, in comparing one school with another, than the rates for respiratory illness among those present in school. The latter rates vary widely, suggesting that the nurses interpret sickness quite differently.
>
> In the first study, at P. S. 39, the sickness in attendance rates were almost zero. In no other school were they so low, and in the second study, when a different nurse was assigned to P. S. 39, the rates were well up with the other schools. Sickness resulting in absence is less likely to suffer through wide variation in diagnosis.

The difficulty of securing reliable data is plainly recognized; the unfortunate

thing is that conclusions are reached and widely promulgated from these data that vary so excessively that they prove nothing except their variability.

Personally, I cannot see that the author is justified in ascribing to ventilation systems the differences in the absence in the different schools. I cannot find that the author has said in so many words that he ascribes the differences in absences to the difference in ventilation systems but it is plainly the inference that the readers are expected to draw from test data as published here and in some of the school magazines.

In view of the fact that the report will be issued under the name of the New York State Commission on Ventilation and will have a tremendous effect on the question of ventilating the schools I feel that the Commission should be requested either to immediately demonstrate that the conclusions are justified by the data or failing to do so should issue a denial of the obvious conclusions of the report.

There are other features of the report which might be commented on at length but I will simply touch briefly on two further points.

The author sees a resemblance in the form of the curve for absences and that for temperature drop below 70 deg. fahr. Careful analysis will show that one curve markedly departs from the other curve and no real resemblance can be fairly shown. Nor can the similarity between the precipitation and the absences be fairly demonstrated. If curves for the separate schools are compared with the precipitation it will be seen that they vary to a still greater extent.

In respect to the old time argument regarding the proper amount of air the author suggests using a lower quantity than 30 c.f.m. per pupil. Many engineers are in favor of a slightly lower quantity and personally I am in this category. However, having an opinion is vastly different from having proof and what we engineers are looking for is a really scientific proof that a lower c.f.m. will give better results. Some of us for years have been operating systems at 20 c.f.m. with what we considered good results; but we must admit that we are still looking for evidence that is conclusive. It takes time, money and skill to get this evidence in acceptable form and we look to the Commission to continue its efforts to get the information needed.

I would like to take this opportunity to state that in some of the tests recorded by the Commission the fans were delivering sometimes more than 25 per cent excess air and everyone knows that it is the excess above the optimum amount which causes much trouble.

In conclusion might I suggest that the Commission be requested to make a suitable authoritative statement regarding this report and that they be requested to continue their investigation making same as comprehensive as possible and repeating tests in the same schools for several years until such time as they can either eliminate variables not being tested or demonstrate that the variables are too widely effective so that this method cannot be satisfactorily used to demonstrate the value of the particular systems being tested.

D. D. KIMBALL: I have no criticism of what has been said. I wish to refer to something of which some of you know about and of which I wish all might know about, and that is the attempt made about a year ago to form a Central Conference Committee on Ventilation, made up of three members of the Society, two of the

Ventilation Commission, one from the *American Public Health Association*, and one jointly from the *American Medical Association* and the *American Education Association*, making seven members, of which W. H. Carrier was made Chairman. This Central Committee was expected to formulate plans to bring together all of those who were interested in investigating and studying the problem of school ventilation.

The first effort was to find a basis of measuring results from. There were those who felt it should be purely on atmospheric conditions of the room, and others who felt those conditions certainly should be determined and recorded, but that the ultimate measure should be based upon the effect on the health of pupils. This movement fell down because there could be no agreement. The final proposal was that this investigation should be made, taking all atmospheric records, all conditions that have even been suggested here or elsewhere, and that similarly the records of the health of the pupils, should be taken, and that the results should be subjected to careful study. We couldn't even agree on that basis.

It seems to me that one of the finest movements that had been started and I (and I know others) felt very badly that it couldn't have been carried through.

JOHN HOWATT: I was glad to hear what has been said and particularly the warning sounded by Mr. West and Prof. Acheson against drawing conclusions on data or figures obtained in the manner that they are bound to be obtained in this sort of an investigation. There are so many factors that cannot be determined accurately, results can be analyzed only with great difficulty.

I was interested in the statement made by Mr. Duffield that children born of American parents appear to be more susceptible to respiratory diseases than those born of foreign parents. I think he comes to that conclusion because he bases his statement on absenteeism from school. I believe the facts are that children born of American parents are probably watched more carefully and it will be found that the child of foreign born parents is sometimes sent to school when quite ill; it requires a serious illness to frighten parents of foreign birth into keeping their children out of school. On the other hand, the American born parents keep them out of school on very slight pretext so absenteeism may not be a true index of illness among school children. Factors of this nature must be considered in attempting any analysis of data obtained in any school population.

Mr. Duffield visited Chicago a little while ago and he was able to get out of it safely although newspaper stories might lead one to expect a different ending. He interviewed our former health commissioner about conducting a series of experiments in ten of our public schools and in an equal number of our parochial schools in Chicago. The number of pupils involved would have been about 30,000. He came to see me and with our superintendent of schools agreed upon ten buildings located so as to represent a cross-section of the races found in Chicago. The buildings tentatively agreed upon have an average equipment as to ventilation and might be considered typical. The preliminary steps were taken, the forms prepared, and general working rules submitted. However, certain changes in personnel and administration affairs took place shortly after this time and nothing has been done further in the study of this problem.

I want to take this opportunity to say that I am a firm believer in the fact that

our worst trouble in ventilation comes from overheating and overcrowding. I believe we overheat our homes, our offices, our bed rooms, and our schools and I am convinced that is one place where we should correct our practice. Overheating in homes should be corrected first, for until that is done and people become acclimated to lower temperatures, we cannot lower the temperature in school rooms without discomfort to teachers and pupils.

C. J. DOUGHTY: Coming, as I do from Toronto, Canada, a city which enjoys somewhat the same climate as Boston, although possibly colder in the winter and sometimes warmer than Los Angeles in the summer, I am very much interested in this paper and discussion.

I was wondering if this committee made any attempt to ascertain the home conditions of the pupils attending these schools. Possibly some of the criticisms made against mechanical ventilation are due to the method of heating the home. We have warm air and steam furnaces in the homes of our American-born children and possibly in a great many cases neither warm air furnaces nor ventilation in the homes of foreign-born children. I think it would be worth while to know this because I, for one, do not believe that the foreign child is any healthier than the American child or the Canadian child. It is a thing of vital importance to our Toronto Board of Education. We have much the same conditions as they have in Boston—in that some of our school caretakers do not operate the ventilation plants and some operate them only for a short time. I think it is unfair to always criticize the mechanical ventilation when it is not given a fair chance. We also have a few schools in Toronto that are ventilated by the open window method.

I would like to know if the committee has taken home conditions into consideration because I believe this might possibly show a big difference in some of our school attendance records.

T. J. DUFFIELD: In reply to Professor Acheson's observations, I want to emphasize certain points which I thought had been made clear in my paper. In compliance with the general procedure in scientific tests, as Professor Acheson has described it, we recognized five variables in the Syracuse School Ventilation Study. They are:

1. Age of Pupil
2. Race-Stock of Pupil
3. Average Classroom Temperatures
4. Incidence of Respiratory Illness
5. Type of Ventilation.

With the restriction of consideration to grades two to six (both inclusive) the age variable is eliminated. With the restriction of consideration to the four schools, with one of each type of ventilation in the same neighborhood, the race-stock variable is eliminated and probably the implied variables of home and food conditions as well.

In the four schools, considered in what I have referred to as the refined results, it so happens that the temperature variable is automatically eliminated. As between the schools under consideration, relative humidity is not a variable, nor is the outdoor weather condition. As I see it, then, this leaves type of ventilation as the only remaining variable affecting the incidence of respiratory illness among the pupils. In view of the fact that every average presented in this report has

been computed from the original figures, there being no averages of averages, I am not prepared to accept Professor Acheson's suggestion that in my interpretation of our findings, I have been "misled by averages."

Further, it may be shown by Table 8 that taken grade by grade, in schools of approximately identical race-stock characteristics, in eight out of ten instances the naturally ventilated school has a lower rate of respiratory illness absenteeism than does the mechanically ventilated school. The ratio of rooms with pupils of a higher percentage of foreign parentage to those with a high percentage of American parentage is the same in the mechanically and the naturally ventilated schools, so the inequality of the number of rooms is equally distributed. Correction for this factor works slightly to the disadvantage of the mechanically ventilated schools in decreasing the effect of the findings from the Seymour School.

It should be pointed out that the rates of total absenteeism, although amply supporting the conclusions drawn, have been used simply as corroborative and not as basic evidence in this study.

Professor Acheson states that I claim to see a resemblance in the form of the curve for absence and that for temperature drop. The fact is just the contrary. On page 121, last paragraph, I have stated that "neither of these curves (the curve of total absenteeism) shows any resemblance to the inverted temperature curve" ..... and further that, "Detailed comparison of the weekly trends of the curves (of respiratory illness under the two types of ventilation and the temperature difference) show so many instances of directly contradictory tendencies as to suggest that, aside from their mutual relationship to the seasonal prevalence of respiratory illness, they have little in common."

On the other hand, the parallelism between the precipitation and absence from respiratory illness in the mechanically ventilated schools has been faithfully demonstrated both graphically in Fig. 6, and mathematically in the next to the last paragraph of my paper.

I have suggested as a result of examination of the findings of this study that a lower rate of air change is probably desirable in the mechanical ventilation of schools. This conclusion can be reached from an entirely different set of facts and a different line of reasoning. I might add that there are two studies now in progress of the effects of mechanical ventilation with reduced air flow. The early indications from one of these studies are highly favorable.

In reply to Professor Acheson's concluding suggestion, it should be stated that the Commission has already made a signed statement with regard to this preliminary study. It appeared in School and Society on December 17, 1927. Further, the study is being continued during the current year in the same schools and in six others as well. Specially trained nurses are making the diagnosis of respiratory illness unless a physician is in attendance, and there is a competent engineer constantly on duty to make observations of the air conditions in the classrooms. Although I feel that all the variables in last year's study have been compensated or eliminated, the repetition of the study is desirable to make certain of these points.

The attempt to discredit the tentative findings here reported by arguing that the apparent advantages of natural ventilation may result from the fact that the children are in school only a very small proportion of the 24 hrs., whereas, they are exposed to varying home conditions, etc., etc., for so much more time each day,

would seem to me to be a rather dangerous method of attack because it carries the implication that school ventilation is not very important anyway.

Mr. West's observation that the present report does not deal adequately with the atmospheric conditions in the various classrooms is a perfectly valid one. The need for more complete data was recognized from the start but practical difficulties prevented their collection during the first year of the study. At the present time, there is a recording wet- and dry-bulb thermometer in each school, and in addition to this continuous record and the temperature records kept by the teachers, the Commission's observer is occupied in making the following measurements in each classroom:

1. Sling Psychrometer
2. Desk top temperatures at center and at corners of the seating section
3. Floor temperature at center of seating section
4. Volume of air supply
5. Volume of air exhaust
6. Temperature of Incoming air.

In addition to these routine observations, determinations of the carbon dioxide concentration and dust content of the air will be made in representative classrooms and the velocities of the air currents in the occupied area of the different rooms will be studied by means of the Kata-thermometer. From our present knowledge of the subject, this should provide satisfactory data regarding the physical conditions of the air in the classrooms.

Reference to my discussion of Fig. 7 in the last paragraph on page 122 will show that I believe the only virtue this chart has is its suggestion that there is some other unfavorable agency (than temperature) at work in the mechanically ventilated schools.

I am somewhat amused by Mr. West's reference to the healthfulness of the little red schoolhouse of our forefathers. It so happens that the Commission has engaged during the last year in a study similar to the one here reported, in 48 classrooms in 1- and 2-room rural schools in one of the upstate counties. The total absenteeism in these rural schools was twice as high, and that due to respiratory illness was more than 50 per cent higher than the corresponding rates for the 3 mechanically ventilated schools in Syracuse.

In replying to Professor Acheson's observations regarding precipitation, I have pointed out that the relationship between precipitation and respiratory illness absenteeism in the mechanically ventilated schools has been demonstrated mathematically as well as graphically. Although the curves of respiratory illness absenteeism are in general parallel to the curve of temperature difference (this will be even more apparent when the data for the autumn months are available), the deviations of the respiratory illness absenteeism in the mechanically ventilated schools from the general trend correspond with the fluctuations in precipitation. I regret as much as does Mr. West the absence of data on air change in the two types of ventilation which would support or discredit the hypothesis, I have suggested to explain the correlation between these two phenomena. I believe, however, that all of us would be greatly surprised if tests showed that the rate of air change in the naturally ventilated rooms was actually higher than in the mechanically ventilated rooms.

Contrary to Mr. West's statement, Figs. 8 to 12, inclusive, have all been based

on Table 12 which deals only with the two mechanically ventilated and the two naturally ventilated schools in which the effects of race stock, age of pupils, etc., etc., have been approximately balanced. If the diagnosis of respiratory illness was only known to be reliable and if the duration of the study was more extensive, the findings presented in these charts would, I feel, constitute conclusive evidence on these points.

In reference to the third point Mr. West emphasizes, the use of the words "check" and "prove" should be carefully defined. This study has been conducted as a problem in scientific research for the discovery of facts, not for the purposes of propaganda, which employs facts only when they support the thesis of the interested party.

In so far as cooperation between the engineers and the health workers in studies of this kind is concerned, I shall be happy to receive frank, detailed criticism of the study reported at this time. And, further, I shall welcome suggestions that will tend to make the current studies of the Commission answer questions that the engineers want answered.

H. C. WESTOVER: I am glad to say that we do not have the real problems of ventilation in the Los Angeles classrooms that you have here. That is, I suppose, a selfish point of view. Our classroom ventilation is simply through windows because we do not have the extreme weather conditions at any time of the year.

Our heating load is early in the morning, most of it before the pupils get to school, and if we have the classrooms warm by the time they are there, and then keep on a moderate amount of heat to hold that temperature, we can open all the windows along the entire side of the classroom anywhere from 4 in. to 1 ft. Heat comes only from wall type radiation installed under all windows, split up, of course to meet the heat loss. We control our temperature condition very well and our classrooms are free from what we have sometimes called the school odor. I have been in a good many of the schools in the Middle West and East and know that their problems are difficult. I really believe that with just the A.B.C. system of open windows and keeping on a little heat we get by in pretty good shape in Los Angeles.

PRESIDENT ANDERSON: The Rochester experiment has been mentioned and maybe Mr. Tracey will say something on the subject.

JOHN TRACEY: It is not right to say that the Rochester experiment has fallen through. The Board of Education is willing to spend $40,000 to fit up the schools in the way that the advocates of the open window system of ventilation would like to have it and in the way that the mechanical or heating and ventilating engineer would like to have. So that we are neutral there. We do not know which way to turn and we are waiting for this committee that Mr. Kimball spoke about to get together and work out some plan by which we can improve on the systems of ventilation that are now available.

H. M. HART: My observation has been that in two homes in the same block, occupied by people in the same class, children attending the same school and playing together when out of school, will show much sickness from respiratory diseases in one house and very little in the other. This clearly shows that much should be considered besides environment, stock and schoolhouse ventilation when we are trying to find out the cause of children's illnesses.

No. 792

APPLICATION OF UNIT VENTILATION SYSTEMS FOR SCHOOLS

By W. R. McCornack,[1] Cleveland, Ohio

NON-MEMBER

BUSINESS and professional men need two kinds of criticism, *first*, that of the cynic whose task it is to strip business of its buncombe, and *second*, the scientific social interpreter whose work it is to point the way to the duty owed to humanity.

Today the architects, engineers and manufacturers who are interested in problems of heating and ventilating buildings have been subjected to the activities of the first type and the thought comes that the second type of criticism should come from within.

A great deal is heard about the laws of the land being congested with much unnecessary legislation, a fact that is undoubtedly true, but on the other hand laws and regulations are necessary and when many of these laws and regulations were enacted they were sane and practical and if they are now obsolete and ridiculous it is because they have not been kept in step with the advancement of the inventions in industry.

Here is a typical case: In Ohio there was a state-wide complaint about ventilation in public school buildings which became so serious as to lead many school and college authorities to either refuse to operate the equipment or to omit it entirely from the buildings. Call it disregard for the law if you will but it is becoming such a potent factor in so many communities that there is now under way and being quietly organized a powerful opposition to mechanical ventilation in schools. This is nation-wide and has a very determined force back of it.

This opposition is not to be regarded lightly and it may be considered as the criticism of the cynic.

The State Code of Ohio which relates to school buildings, theatres and assembly halls was written as a result of two disasters. *First*, the Collinwood school fire in Cleveland and *second*, the Iroquois theatre fire in Chicago.

After careful study many of the architects in Ohio felt that the code was not only too stringent but that it had become obsolete.

It was proposed to liberalize it. Many makers of ventilating equipment opposed

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Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, January, 1928.

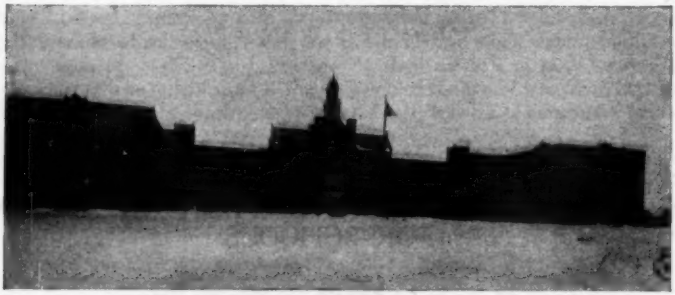


FIG. 1. THE CLEVELAND HEIGHTS HIGH SCHOOL

any change, but it is believed that it has been the most constructive bit of legislation with respect to the construction industry ever passed in Ohio. Why should

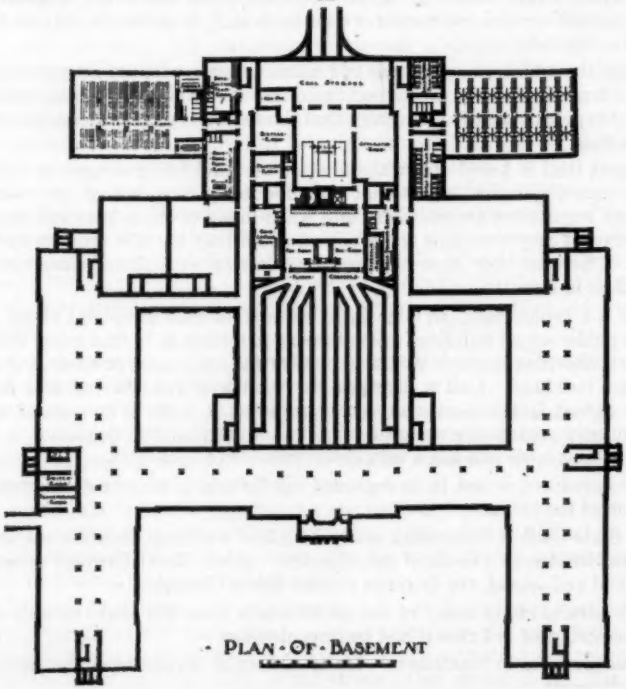


FIG. 2. PLAN OF BASEMENT

a legislature attempt to fix the point of inlet for fresh air? The new types of ventilation now in use due to this change are meeting with success and the public is thinking that perhaps there is something to the matter of mechanical ventilation after all.

In the Caledonia school in East Cleveland, O., a unit system of ventilation is in

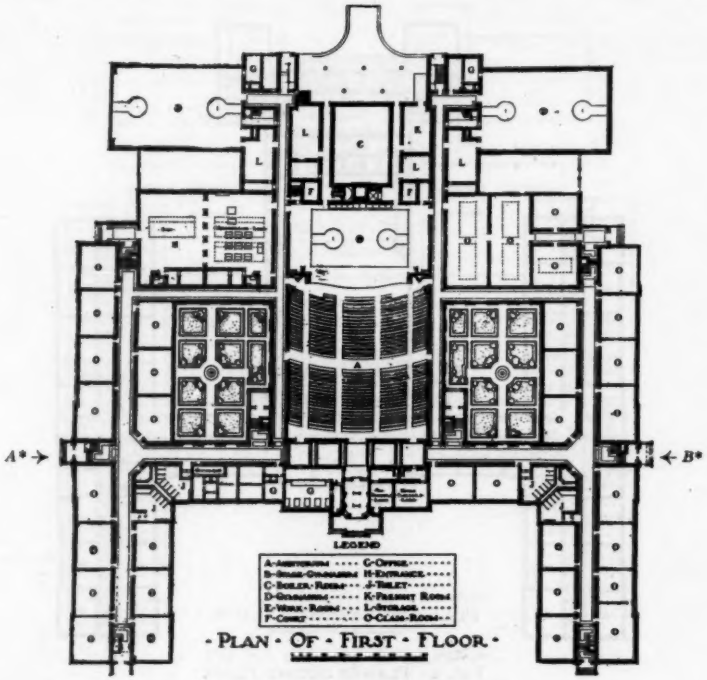


FIG. 3. PLAN OF FIRST FLOOR

operation which supplies *first*, fresh air without drafts, *second*, temperature regulation which keeps the temperature at the point desired by the medical staff, *third*, there are no odors, *fourth*, the teaching staff is perfectly satisfied.

Further than this the corridor venting idea has been carried out with excellent results.

In Ohio the code was violated in order to try out the unit system of ventilation which was later adopted and now corridor venting is being tried out in violation of the code and many think this further change should be made in the law.

* The wings above points *A* and *B* are for future growth.

For the purpose of applying the second or social scientific type of criticism to the problem, let us examine the heating and ventilating layout in a large high school, the Cleveland Heights High School, and consider it as criticism from within.

The building has a total cubic content of 2,700,000 cu. ft. and contains 54 classrooms, general offices, doctors offices, rest rooms, library, cafeteria, band room,

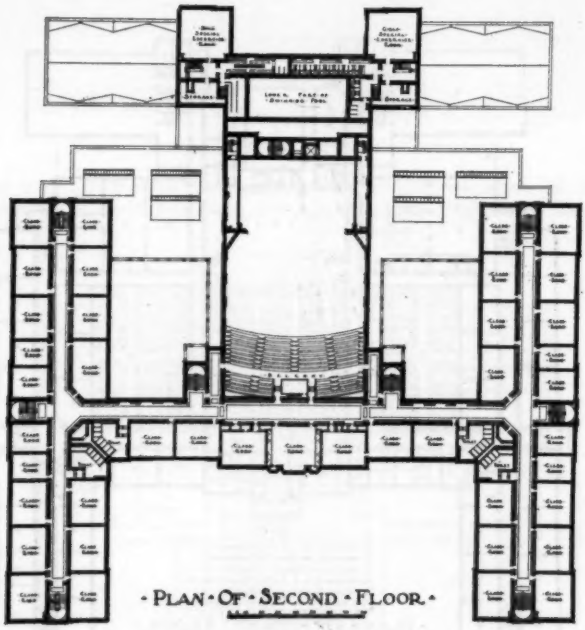


FIG. 4 PLAN OF SECOND FLOOR

chorus room, kitchen and serving rooms, natatorium, boys' and girls' club rooms, boys' and girls' special exercise rooms, woodworking rooms, boys' and girls' gymnasia with showers and locker rooms, auditorium and stage gymnasium.

Fig. 1 shows the school, and Figs.* 2, 3, 4, 5 and 6 are the floor plans and are self-explanatory following the preceding paragraph. The plan, Fig. 7, shows a layout of the central ventilating system and Fig. 8 shows a unit ventilator in a typical room, Fig. 9 is a plan of the boiler room, and Figs. 10, 11 and 12 are views of the mechanical equipment.

The auditorium has a seating capacity of 2000 and by using the stage an addi-

* These plans show the building when finally complete.

tional 500 can be seated. The stage is large enough for a standard basketball court. Games can thus be played on the stage while the spectators occupy comfortable seats in the auditorium.

Several separate ventilating systems are provided for various parts of the building. Heating is by direct radiation in classrooms and special rooms. In the

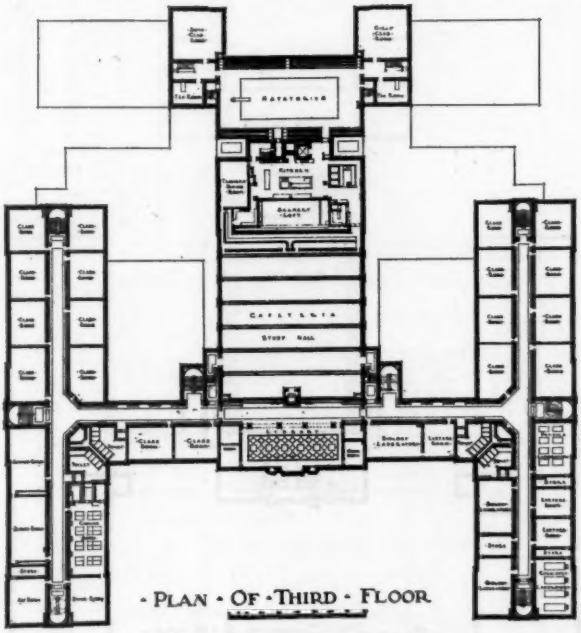


FIG. 5. PLAN OF THIRD FLOOR

classrooms an interesting dual control arrangement using both unit heaters and radiators, maintains the healthful condition with economy, as will be explained later.

Separate Ventilating Systems

The ventilating system for the auditorium includes two 16,500 c.f.m. multiblade supply fans and one 20,000 c.f.m. exhaust fan. Fresh air, taken from the roof through a large air shaft, is carried down below the stage, where it passes through two supply fans (Fig. 7) with their respective units of heaters and discharges into air tunnels passing beneath the auditorium floor. Heated air is admitted into the auditorium through adjustable mushrooms beneath the seats. Exhaust air is taken out through the ceiling grilles worked into the beam construction and also

through grilles under the balcony ceiling. Grilles under the balcony ceiling have automatic dampers, controlled by a special thermostat that will open them if the air under the balcony becomes too hot. Provision has been made by automatic air-controlled dampers for recirculating the air in the auditorium to cut the cost of heating this room to a minimum when ventilation is not required.

The boys' and girls' gymnasia are supplied with fresh air by separate fans

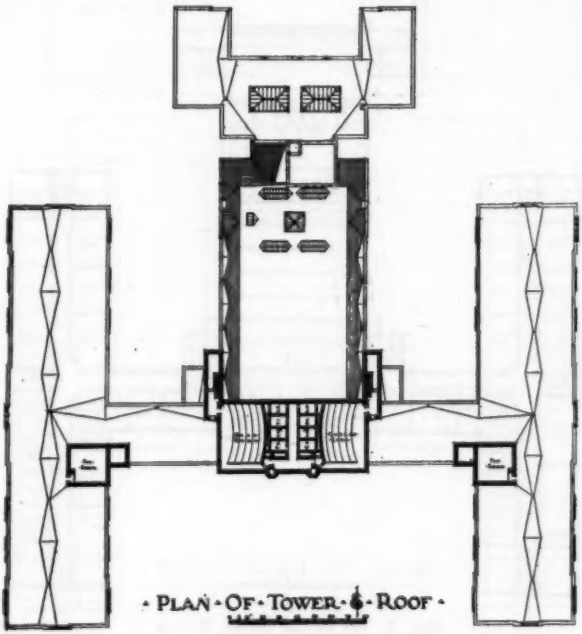
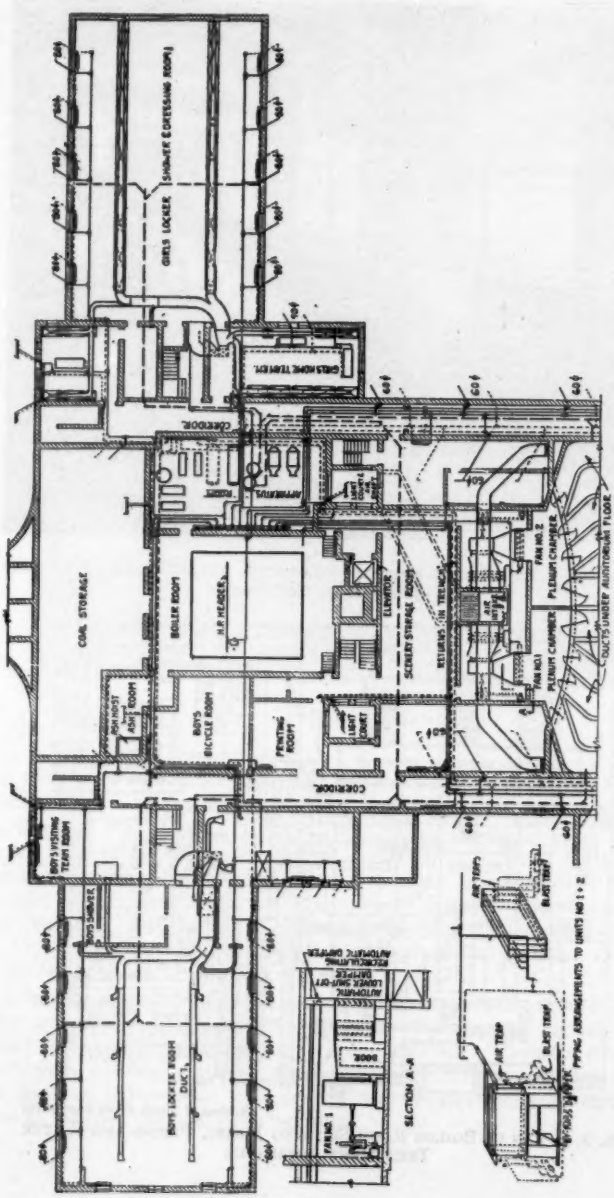


FIG. 6. PLAN OF TOWER AND ROOF

each having a capacity of 9000 c.f.m., taking fresh air from the roof and discharging it downward into the gymnasia and their separate locker rooms. The exhaust from these rooms is carried up to two exhaust fans on roof, each having a capacity of 6500 c.f.m.

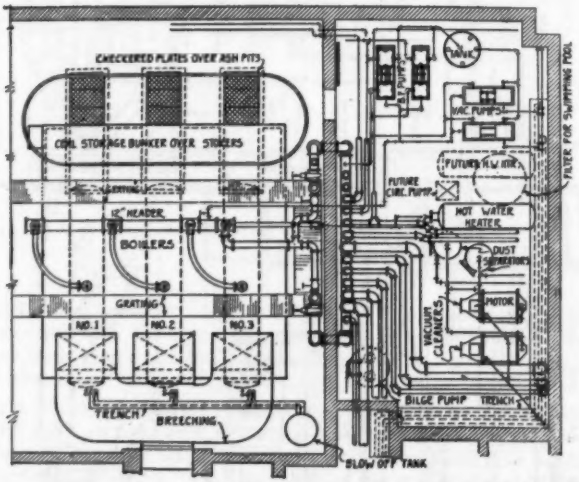
Classrooms, library, cafeteria, natatorium, band room and chorus room are supplied with fresh air from unit heaters in each room, and the vents from these rooms are carried up to trunk duct systems, above the third floor ceiling, from which two exhaust fans pull. Each exhaust fan has a capacity of 24,000 c.f.m., there are 12 heaters of 1200 c.f.m., 43 of 900 c.f.m. capacity and 8 of 500 c.f.m.



Courtesy of Power Plant Engineering

FIG. 7. LAYOUT OF CENTRAL FAN SYSTEM AND SOME PIPING DETAILS

FIG. 8. UNITS AND DIRECT RADIATORS COORDINATED FOR OPERATION UNDER THERMOSTATIC CONTROL



Courtesy of Power Plant Engineering

FIG. 9. PLAN OF BOILER ROOM SHOWING PUMPS, PIPING AND WATER TREATMENT APPARATUS

capacity. Each heater is provided with mixing dampers, shutoff dampers and recirculating dampers.

Unit Heaters and Radiators under Control of Two Thermostats

These unit heaters in each room together with the radiators are under the control of two thermostats, one controlling the mixing dampers on the heater cabinets and the other controlling the steam valve on the radiator. In the smaller rooms one heater is installed without a radiator adjacent to it. In some of the larger

FIG. 10. STOKERS AND BOILERS

rooms, such as the combination cafeteria and study hall shown in Fig. 8, there are several heaters and several radiators. Their operation is as follows:

The thermostat controlling the mixing dampers of the heater is set up to keep the room temperature within one degree of the 70 deg. limit of the thermostat. If a sudden change occurs in the outside temperature (as it frequently does in the lake cities) causing the temperature to drop to 68 deg. or lower, the second thermostat begins to supply steam to the radiator to keep the temperature up to 70 deg. The latter thermostat is intermediate in its action, opening the radiator valve gradually and thus avoiding overheating the room.

As a further control on the unit heater, if the temperature should drop to 60 deg. for any reason—such as insufficient steam—the fresh air damper will automatically close and the recirculating dampers will open. Thus the room air will be recirculated to bring up the temperature quickly to 65 deg., and then the action of the dampers is reversed. This scheme also reduces fuel consumption when heating up the cold building in the morning.

There are two toilet exhaust fans each of 1800 c.f.m. capacity, pulling from boys' and girls' toilet room sections of the building. The woodworking room is provided with an exhaust blower of 4300 c.f.m. piped to the various machines and discharging shaving and saw-dust to a collector in the boiler room. Kitchen and serving room quarters are provided with a 5000 c.f.m. exhaust fan with special hoods over ranges, counter tables and dishwashing machine.

Well Equipped Boiler Plant Supplies Steam

For supplying steam to the heating and ventilating system, a well equipped boiler plant is installed, Fig. 10. All electric power is purchased.

The total combined equivalent load in direct radiation is equal to 95,165 sq. ft.

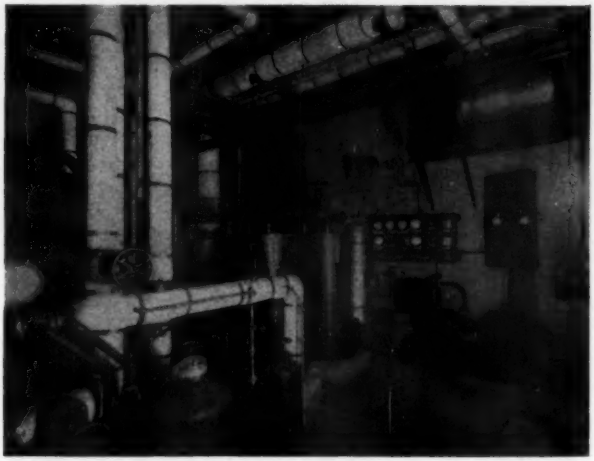


FIG. 11. APPARATUS ROOM

divided as follows: direct column radiators, 21,565 sq. ft., unit heaters 22,980 sq. ft., heating coil for auditorium and two gymnasium supplies 28,120 sq. ft., one 3000 gallon domestic water heater, 10,500 sq. ft., one 6000 gallon swimming pool heater, 12,000 sq. ft.

Steam for these is generated at 60-lb. pressure in two 240 hp. vertical bent tube boilers, fired by natural draft stokers with extended settings. Space is provided for a third boiler in the future. Draft control automatically adjusts the speed of the stoker engine to give proper combustion and feed water regulators control boiler water level. Each boiler is equipped with soot blowers, blow-off valves, non-return valves and gate and globe valves.

Figs. 10, 11 and 12 are photographs in the boiler room and apparatus room,

respectively. Coal is delivered to the bunker over the extended fronts of the stokers by a coal hoist and electric monorail system. Ash is removed to grade by a sidewalk-type elevator.

High pressure steam is used for kitchen equipment, bathing suit dryers and sterilizers and hot water generators. Steam for the general heating system is reduced from 60 lb. to 5 lb. through reducing valves into a 16-in. low pressure header, from which separate valved lines are carried to classroom sections, general offices, auditorium, gymnasia and swimming pool section.

The return system is of the vacuum type with thermostatic traps in all radiators,

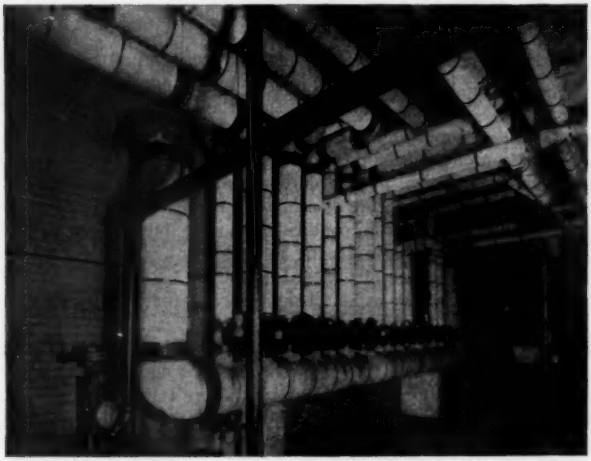


FIG. 12. STEAM CONTROL

unit heaters and drips and heavy duty blast traps on all stacks. Returns are brought back to a return header in the pump room, to which are connected two 10 x 12 x 12 in. vacuum pumps, arranged so that either or both can be used. Each pump is controlled by vacuum regulators. The vacuum pump discharges to a storage receiver with auxiliary cold water feed for makeup water.

The 10 x 7 x 12 in. duplex boiler feed pumps take the water from the storage receiver and discharge it to the boilers through a feed water filter. Each boiler has an auxiliary water feeding system through a water injector.

The dual system of heat control was installed with four separate divisions from a central distributing panel, one system to the school classroom section, one system to the auditorium, one system to boys' and girls' gymnasia section and one system to the swimming pool section. The dual control system permits rooms that are not being used to be kept at a lower temperature than those in use, thus saving fuel.

Central vacuum cleaning equipment system consists of two four sweeper machines arranged so that whenever one machine cannot carry the load, the second will start automatically and run as long as required.

The heater for domestic use, showers, kitchen and lavatories is of the multi-coil storage type, capacity 3000 g.p.h. and storage 1000 g.p.h. The 6000 g.p.h. heater for the swimming pool is of the instantaneous type.

The swimming pool has a capacity of 60,000 gallons. All water used for swimming pool is first passed through a 6000 g.p.h. water softener and then through an 8000 gallon filter. Water from the pool is recirculated by a double suction 125 g.p.m. centrifugal pump. The water is sterilized by a chlorinator. Bypass piping is arranged so that all water for the domestic hot water system of the building can be put through the water softeners if desired.

It is interesting to note the result of placing the swimming pool directly over the boiler room. The heat from the boiler room keeps the water in the pool at the required temperature practically all of the time at a considerable saving of fuel.

This general discussion will serve to introduce the subject of results obtained from the installation of a mechanical system of ventilation in a large high school. The scientific and mechanical phases of the question do not interest the owner as his interest is centered in securing satisfactory results both from the standpoint of healthful and comfortable room conditions and economy of operation, and upon these facts, the building public is basing its judgment of mechanical ventilation. The many instances of failure of ventilating systems to function has set up the counter movement against the expenditure of money for ventilating equipment.

To be quite honest in the matter it must be admitted that while the general results obtained in heating and ventilating this building are probably an average result or, better, they were not as satisfactory as they should have been in the face of the general feeling against ventilation, and before the architects and engineers became fully aware of the situation the building had become a battle ground in which those who had installed equipment and those whose equipment is manufactured to do a similar work were met in a commercial and not a scientific conflict. This is the easiest way to create suspicion on the part of the owner toward all apparatus connected with ventilation.

It is not a question of the merit of one fan over another, one unit over another, one temperature control over another, one type of trap over another, but it is the bigger question of determining that the basic principles are right, that the design in all its details has been laid out in accordance with common sense and good practice and that the operating engineers had been thoroughly instructed how to operate the plants in order to secure the results desired, for mechanical ventilation has its value only when it does the work required of it in a satisfactory manner. Ventilation can be legislated into a building but it cannot be made permanent unless the architects, consulting engineers, medical people, school people and manufacturers first determine the room conditions desirable to obtain and then set about to design a system which is simple and practical in its operating elements.

It will have been seen by the drawings that this high school is a very large one and with the installation of the unit system of ventilation in all the classrooms and laboratories that there might be some elements in the design that could be readily overlooked.

Engineers are all familiar with the condition often written into a specification that the heating contractor shall guarantee certain results from the plant when this contractor has no control over what the plant will do providing he follows drawings and specifications, as he is only the agent to carry out the engineers' ideas. The responsibility does not cease until the engineers have prepared a complete set of operating instructions which shall tell the operating force in the building how to obtain the best results from the plant which is installed.

In the case of this building the chief difficulty was overheating. A careful investigation of the building showed us, *first*, that there was a great amount of uncontrolled heat due to the large uncovered risers. This appears to be a condition relating to the size of the building since two other buildings with similarly designed plants but much smaller were not affected in this manner. This trouble occurred largely in the first floor rooms and covering the risers in one of these rooms brought down the control of the temperature in that room to a reasonable point. Searching further it was found that the control valve at the header would not operate to reduce the pressure sufficiently low to take care of reducing the heat circulating in the supply lines during mild weather. With this change made it will be unnecessary to cover the risers in the building because the reducers at the headers will eliminate the superheated steam in the mains which had been causing the trouble.

It is a well-laid-out heating and ventilating plant but is an example of the lack of cooperation which often produces conditions of this sort in buildings containing mechanical ventilation.

It is my belief that mechanical ventilation can be made to function perfectly at a reasonable cost to the owner. But this cannot be done unless there is better cooperation on the part of the architects, engineers, manufacturers and operators of these plants and not even then will the proper results be obtained until the health authorities come to a decision as to what conditions are necessary in a room to produce the maximum health and comfort.

This paper is not a scientific treatise but touches only in a superficial way that side of the question. It is a plea, however, for the cooperation of all organizations interested in proper air conditions in buildings to bring about proper results through an unbiased and fair-minded controversy. There is no merit in an architect or an engineer maintaining that a ventilating plant is perfect when it is not. There is no merit in one manufacturer attempting to prove that his apparatus will function where another has failed if the basic principles of the plants are defective. This working at cross purposes tends to create uncertainty in the minds of the building public and suspicion is directed to all who are interested in the design, manufacture and installation of heating and ventilating equipment.

A great deal is heard about legislative action, but personally I am in favor of passing no new legislation nor in altering the present until the matters in question have been settled on a scientific basis. I believe that a campaign of education instead of a campaign for selling will be the most effective way to preserve that which is good in this work in which we are all interested.

Here is an example which is not offered to prove that one system is better than another but to show the difference between two buildings, one designed primarily for the unit system and the other for the central fan. They are cold figures and

in the case of the central fan building it is undoubtedly true that some of the waste area is due to poor engineering and careless planning.

	HIGH SCHOOL A			HIGH SCHOOL B		
Educational	107,595 sq. ft.	59.68%		100,912 sq. ft.	49.37%	
Corridors	32,037 sq. ft.	17.76%		42,284 sq. ft.	20.69%	
Administration	18,246 sq. ft.	10.12%		26,003 sq. ft.	12.72%	
Walls, duct, etc.	22,430 sq. ft.	12.44%		35,219 sq. ft.	17.22%	
Gross area	180,308 sq. ft.	100.00%		204,418 sq. ft.	100.00%	
	Sub-division of Educational Areas					
Classroom lockers, etc.	47,048 sq. ft.	26.10%	43.73%	62,745 sq. ft.	30.65%	62.08%
Physical education	33,016 sq. ft.	18.31%	30.69%	13,230 sq. ft.	6.47%	13.11%
Auditorium	15,834 sq. ft.	8.78%	14.72%	14,757 sq. ft.	7.22%	14.62%
Cafeteria	11,697 sq. ft.	6.49%	10.86%	10,185 sq. ft.	5.03%	10.19%
Total	107,595 sq. ft.	59.68%	100.00%	100,917 sq. ft.	49.37%	100.00%
	Sub-division of Administration Areas					
Custodial	8,916 sq. ft.	48.87%		18,840 sq. ft.	72.45%	
Educational	3,557 sq. ft.	19.49%		3,643 sq. ft.	14.01%	
Toilets	5,773 sq. ft.	31.64%		3,520 sq. ft.	13.54%	
Totals	18,246 sq. ft.	100.00%		26,003 sq. ft.	100.00%	
Fan rooms	3500 sq. ft.			9500 sq. ft.		
Cube	2,700,000 cu. ft.			3,450,000 cu. ft.		

This shows the great amount of space used by ducts and walls and in fan rooms. As a concrete example this proves that of these two buildings the unit system is much more economical but it does not prove that a central fan system could not be laid out much more economically than this one was.

Superficiality is a curse and it is the combined efforts of all seeking for facts and facts alone that will bring order out of the present ventilation chaos.

"We require from buildings, as from men, two kinds of goodness: *first*, the doing their practical duty well; then that they be graceful and pleasing in doing it; which last is itself another form of duty."—*Ruskin.*

DISCUSSION

A. W. LUCK (READING): This is the first time that I have made an attempt to address an audience of this nature, although I have attended a good many of these conventions. We have discussed the location of radiators, describing radiators in their several different phases, but I have had considerable experience in placing radiation at ceiling and also under the windows. Sometimes a suggestion may come from an unexpected source. In schoolroom ventilation with the open-window

method my suggestion would be to distribute your radiation about 60 per cent under the window and 40 per cent at the ceiling. Admit your fresh air at the top of sash rather than at the bottom. The ventilation will be taken care of as is customary through vent flues with opening at floor. The temperature control you can take care of through the lower unit, leaving the radiation or the surface at the ceiling to take care of the temperature under conditions of mild weather. At the same time we admit the necessary amount of fresh air. With such a distribution of heat on the exposed sides of the room it is possible to pull down the upper sash, ventilate the room without feeling a particle of draft at the floor. I have also experimented and found it to be a fact in an experimental room that if you take three radiators, one at the floor, another one about half-way up to the ceiling and one at the ceiling, preferably laid horizontally, you will find that your floor will be just as efficiently heated with the upper radiator in service. It will take less surface actually to produce the same result and it is entirely out of the way. There are cases where floor space is a valuable asset and by taking the radiation off the floor and placing it out of the way, you can secure your results.

I mention one specific case. I have a building 45 feet high with monitor roof where all of the heating is done from overhead. I have other cases of roundhouses, machine shops, foundries, etc., some with a bad roof condition and yet the workmen are very comfortable with the overhead method.

I present these facts that they may bring out a new line of thought and a way whereby we may test direct radiation and give the results to the Society. It is only by bringing our own actual experiences before a body of this kind that we can hope to get anywhere. It is results that count.

E. B. LANGENBERG: In the work of the Citizens Smoke Abatement League in St. Louis we have done something that possibly has never been done in any other city. We started in with about five or six sub-committees. One is an educational committee. We established a course of heating and ventilating in the schools from the high school up, that is commencing to show results. We also established a course of instruction for janitors and the surprising result is this: In the opinion of 17 engineers the average janitor and the average householder is not developing over 42 per cent efficiency out of the plant he is firing. Since we have started this school and have this technical committee from the local chapter and among the consulting engineers of St. Louis we are getting that efficiency up a great deal higher. In some cases it is going up to as high as 60 and 65 per cent, which is very high considering that we have to burn soft coal to a great extent in the City of St. Louis.

Those results give me an idea and that is if the local chapters all over the United States would establish schools of instruction for the men that are going to use some particular apparatus they would be a lot better off than where they put the apparatus in and turn it over to some politician to run. If you have one man on the Board of Education that gets back of these men and tells them what they have got to do and how they have got to do it, it can be done. It is simply a matter of organization—ten or twelve men on a Board to get behind the one man and see that the orders are obeyed. Mr. Hallett is doing a wonderful work in St. Louis. Our health records show an improvement over the previous condition where we

had open-window ventilation, but a lot of people will say, "Those figures are distorted." The fact is that the Health Commissioner's report, which is entirely a separate organization, certified to these figures and they certainly mean something.

No. 793

AIRATION OF INDUSTRIAL BUILDINGS

By W. C. RANDALL,[1] DETROIT, MICH.
MEMBER

THE wind, is the chief motive force utilized in the airation of a building by natural means. It forces air in by way of certain openings, through the building, and out by other openings. If the building is one in which heat is produced, and in practically all buildings this is so, the warmer air inside has a tendency to rise, due to its buoyancy, and this also assists in the airation. These two forces may aid or oppose each other, and it is essential that they be coordinated and controlled, and the air changed in the zone of occupation if a building is to be successfully airated.

It is astounding the great volumes of air that can be moved into and out of a building by the forces of nature. By great volumes, is meant just exactly that, for on field surveys of at least three industrial buildings air flows of more than 3,000,000 cu. ft. of air per minute were measured. However, it is not great volumes that are of such a momentous import as the correct volume, adequately controlled.

Contrary to the popular phrase variable as the wind, the wind is reasonably consistent in its direction and velocity. Weather reports show that for each locality in the United States there is a prevailing wind, the direction of which holds constant for many months at a stretch, and for the same group of months year after year, and that the average velocity varies within comparatively small limits throughout the year.

The tendency of warm air to rise and be replaced by cooler air, or the reverse of this, if one is to be strictly accurate, the tendency of cold air to fall and force up the warm lighter air, follows natural laws that have been known for some time. It would seem, then, that the problem has resolved itself into one of little better understanding of the behavior of the wind, acting alone or combined with the flow created by temperature difference, since most of the idiosyncrasies of natural ventilation occur when the flow due to the motive force of the wind is opposing the flow induced by temperature difference. As a matter of fact, some of the peculiar things that happen in mechanical ventilation and heating can be traced to the fact that the wind is cooperating with or opposing the action of the mechanical system.

Since windows are generally used to incorporate airation into the building design,

[1] Chief Engineer—Detroit Steel Products Co.

Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

it is only logical to say that the company with which the writer is connected should be called upon by the architect and engineer to cooperate in the solution of the problems involved. This problem of airation was turned over to the Department of Engineering Research at the University of Michigan with Professor Emswiler in charge. Incidentally the problem of daylighting was similarly handled under the guidance of Professor Higbie. The result is that the company's engineers are now able to pre-determine the flow of air into and out of a building, by the natural forces, wind and temperature difference, with a reasonable degree of accuracy.

TABLE 1. AVERAGE VELOCITIES AND DIRECTIONS OF THE PREVAILING WINDS FOR THE SUMMER MONTHS AT TYPICAL LOCALITIES IN THE UNITED STATES

Location		June		July		August		Average	
State	City	m.p.h.	Dir.	m.p.h.	Dir.	m.p.h.	Dir.	m.p.h.	Dir.
Ala.	Birmingham	5 4	S	5.1	S	4.8	S	5.1	S
Ariz.	Phoenix	5.1	E	5.1	W	4.6	E	4.9	E
Ark.	Little Rock	7.5	S	7.1	SW	6.6	NE	7.1	
Cal.	Los Angeles	5.0	W	4.8	W	4.7	W	4.8	W
	Fresno	8.3	NW	7.4	NW	6.7	NW	7.5	NW
Colo.	Grand Junction	6.7	SE	6.0	SE	5.9	SE	6.2	SE
Fla.	Miami	7.5	SW	7.1	SW	7.4	SW	7.3	SW
	Tampa	6.1	NE	5.6	E	5.4	NE	5.7	NE
Ill.	Chicago	15.0	SW	12.0	SW	12.0	SW	13.0	SW
Ind.	Indianapolis	9.2	SW	8.4	SW	8.0	SW	8.5	SW
Idaho	Boise	5.3	NW	4.9	NW	4.5	NW	4.9	NW
Iowa	Des Moines	7.1	SW	5.9	SW	6.2	SW	6.4	SW
Mass.	Boston	9.3	SW	8.4	SW	9.2	SW	9.0	SW
Mich.	Detroit	9.9	SW	9.5	SW	9.2	SW	9.5	SW
Mo.	Kansas City	9.1	S	8.1	S	9.1	S	8.8	S
Nebr.	Omaha	7.8	SW	6.8	SW	7.5	SW	7.4	SW
N. Y.	New York	13.0	SW	13.0	SW	14.0	SW	13.3	SW
	Albany	6.7	S	6.3	S	5.9	S	6.3	S
N. C.	Charlotte	5.3	SW	4.9	SW	4.7	SW	5.0	SW
Ohio	Columbus	9.5	SW	8.6	SW	8.5	SW	8.9	SW
Ore.	Portland	5.9	NW	5.9	NW	5.5	NW	5.8	NW
S. C.	Charleston	10.4	SW	9.7	SW	9.3	SW	9.8	SW
Va.	Richmond	6.4	SW	6.4	SW	6.0	SW	6.3	SW
Wash.	Seattle	8.1	S	7.3	N	6.6	N	7.3	N
	Walla Walla	6.0	S	5.7	S	5.2	S	5.6	S
Wis.	Milwaukee	9.3	NE	8.4	NW	10.4	NW	9.4	NW

In this paper the presentation will be confined to those things which affect the movement of air and any reference to the movement, except that of common air from the outdoors, through the buildings and out again by natural agencies will be carefully avoided. While airation is synonymous with ventilation in a wide range of conditions, manifestly it is not a cure-all, and mechanical methods of ventilation must be resorted to, since in a great many cases it is the only practical answer. No effort will be attempted to visualize the benefits of ventilation; or otherwise trample on the just field of the physicians, the psychologists, and the engineers who have worked and are still doing research work on the effect of such things as temperature, humidity, air motion, etc., on a man's productive capacity. A great deal has been said in prose and poetry about the gentle zephyrs of springtime and perhaps poetry may still be written about the soft breezes in, through and out of an industrial building, but that will be left to the poet. The author will

adhere strictly to an engineering analysis with the assumption that a better knowledge of airation is desirable, whether the building is to be ventilated by mechanical means, by natural means, or the combination of the two.

The results of the research fall into two general groups.

1 A basis for predetermining the flow of air due to:
- *a* The wind
- *b* Temperature difference
- *c* Combination of temperature difference and the wind

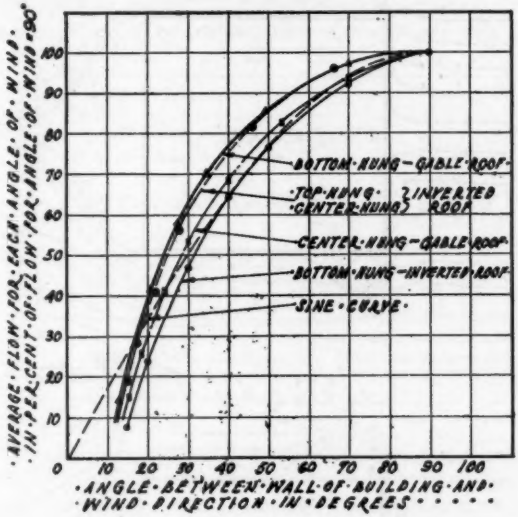


FIG. 1. FLOW OF AIR DUE TO PRESSURE EFFECT OF WIND, VARYING APPROXIMATELY WITH THE SINE OF THE ANGLE—BETWEEN DIRECTION OF WIND AND FACE OF BUILDING

2 Information on those factors which influence the flow of air such as:
- *a* The size of the inflow and outflow openings
- *b* Type of windows
- *c* Angle of opening of pivoted windows
- *d* Slope of roof

Flow Due to the Wind

As previously stated, the wind is not only a powerful motive force but also quite a consistent one. From the Weather Bureau reports covering the average velocity and direction of the prevailing winds were obtained for every month at various typical localities in the United States. A survey of these data quickly showed the general uniformity in the direction of the prevailing wind and the small range

of the average velocities for each locality, as is shown in Table 1, covering a small part of the data received from the Weather Bureau. As a matter of fact, absolute consistency may not be as desirable as reasonable variation in the velocity.

Industrial buildings in which the manufacturing process produces little heat, must depend entirely on the wind for natural airation. The airation is usually

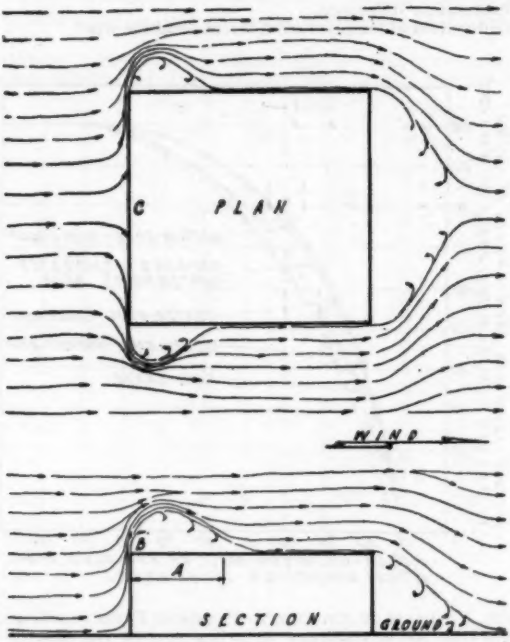


FIG. 2. THE JUMP OF WIND FROM WINDWARD FACE OF BUILDING. (*A*—LENGTH OF SUCTION AREA; *B*—POINT OF MAXIMUM INTENSITY OF SUCTION; *C*—POINT OF MAXIMUM PRESSURE)

accomplished by the air blowing through the building, coming in and going out through the open windows and doors in the sidewalls; in through openings in the sidewalls and out through openings in the roof; and in some cases in through the roof openings and out through other openings in the roof and the sidewalls.

The wind forces air into the building usually through the openings on the windward side. This pressure so developed usually pushes the air out by way of openings on the leeward side, or even through openings on the windward side of less pressure.

The velocity of the air through the window openings, due to the pressure effect of the wind, depends upon and varies, for all practical purposes, directly with the speed of the wind. In all cases the velocity through a window opening will be less than the speed of the wind, and under few conditions will it be less than half the speed of the wind, that is, if there are adequate openings for outflow.

The volume of air flow depends on the velocity of the wind, its direction with relation to the face of the openings, the number and size of the openings, and the resistance to flow built up by obstructions in the openings. The greatest flow will usually be secured when the building is so oriented that the prevailing wind blows directly against the wall having the greatest opening areas.

The pressure built up and consequent inflow varies closely with the sine of the

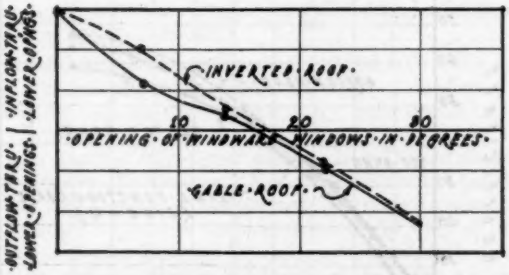


FIG. 3. CURVES SHOWING EFFECT OF OPENING WINDWARD WINDOWS OF MONITOR WITH TOP-HUNG OPEN-OUT WINDOWS LEEWARD SIDE LEFT OPEN 30°

angle between the wind direction and the building face, particularly between 20 deg. and 90 deg. or perpendicular to the building, as is shown on Fig. 1.

The wind pulls air out of a building, through the openings in the leeward side and through those openings near the windward face where there is a condition of vacuum caused by the wind hitting the windward face and jumping out around the adjacent sides or up over the roof at that point. This jump of the wind and suction area thereby developed is illustrated in Fig. 2. Within the regions enclosed by these stream line arcs, there exists a strong suction near the windward face, gradually diminishing to zero at a point somewhere near the reconvergence of the lines of parallel flow. This suction effect is illustrated in everyday life when the driver smokes in a closed automobile. When the glass in the door at his left is dropped the smoke is pulled out through the opening near the inside face of the closed windshield.

The jump of the wind from the face of a building is necessary for the production of a vacuum or suction. This jump or splash, or hop or whatever it is termed, and subsequent re-establishment of parallel flow further down-stream completely accounted for some hitherto unexplained actions of the wind, and forced revision of many earlier erroneous assumptions regarding wind action. It had been thought that a strictly parallel flow of air along the face of a building containing openings

would induce flow by means of the drag or engagement of particles of air from within by the swift moving particles without. Possibly some such action does take place, but if so, it is a minor and negligible factor in comparison to the effect of the jump. This indicates that there is a distinct disadvantage in running a monitor parallel to the prevailing wind, since parallel flow of the wind does not create suction and only in the windward end of the monitor under the jump of the wind are suction openings. On the other hand, there is an advantage in running a monitor perpendicular to the prevailing wind so that there will be suction openings in the lee side.

The suction created by the jump of the wind is more responsible than any other factor for some buildings airating and others more or less identical in design and

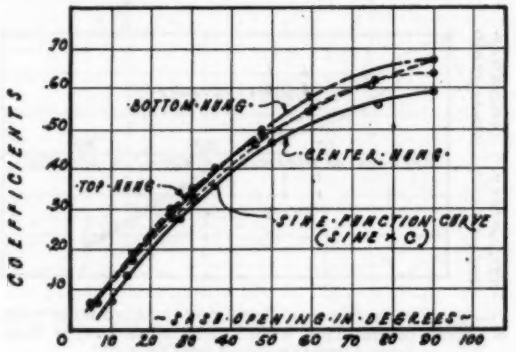


FIG. 4. CURVES SHOWING COEFFICIENTS OF RESISTANCE FOR VARIOUS DEGREES OF OPENINGS OF THREE TYPES OF PIVOTED STEEL WINDOWS

fenestration not airating. In other words, buildings will airate if designed and correctly oriented to take advantage of the prevailing winds to create suction where needed. In the design and orientation of a building, if it is to have efficient airation the plan must be directly counter to the aims of the ship-builder, to whom perfection of design lies in the creation of stream-line parallel flows along the ship's side to reduce to a minimum the suction and consequent drag at the stern. What must be achieved, if the wind is to be used as a ventilating agency in buildings, is absence of the natural effect of stream-line flow, and the presence of a distinct, powerful suction area and carefully planned control of the openings in this area.

The length of the jump or hop of the wind, and consequent suction area, is determined by the height, width and area of the windward face of the building. This applies for all combinations of width and height up to the point where the width is greater than about nine times the height, beyond which the width loses its influence and the height seems to be the predominant factor. These general conditions also prevail in the case of a monitor or other obstruction on the roof which would develop a secondary jump. The nearest thing to a general statement that

could be made is that the length of the jump is a function of the square root of the area of the windward face.

The length of the jump does not depend upon the velocity of the wind. In other words, the suction area is independent of the variable velocities of the wind. This simplifies the problem of placing heat producing processes so that the smoke, gases, etc., will be removed by the suction effect of the wind, since this area is determined only by the general dimensions of the elevations of the building, particularly that elevation facing the direction of the prevailing wind.

The intensity of the suction, or the vacuum produced in the jump of the wind varies with the square of the speed of the wind. The intensity is greatest just back of the building face which produces the jump, and gradually reduces to zero as the lines of parallel flow are re-established. Incidentally the velocity of the flow varies with the square root of the intensity of the vacuum, and is, therefore, directly proportional to the speed of the wind.

The height of the jump and consequently the height of suction area is a rather complicated function, chiefly of the speed of the wind. It is affected by the dimensions of the building somewhat the same but to a lesser degree than is the length of the jump. While up to the present time this function has not been expressed satisfactorily in a formula, still a great deal has been learned about the action of the windward windows of a monitor. If the sidewalls of the building were high, and the monitor low, it is quite possible that the windows in the windward side of the monitor would be outflow openings because the wind of normal velocity would jump clear of the monitors and the entire monitor would be in a suction area. As the proportion changed, that is, the height of the monitor increased and the height of the sidewall decreased, perhaps the upper openings in the monitor would be inflow openings and the lower openings outflow. However, the average condition would usually make the openings on the windward side of the monitor inflow openings.

The velocity of the flow of air through openings in the leeward side of a building varies with the speed of the wind, and is in general approximately 75 per cent of the velocity due to the pressure effect of the wind of the same speed.

In Fig. 3 the curves indicate the effect of opening the windward windows of a monitor. The top-hung, open-out windows in the leeward side were left open 30 deg. during the test. As the windward windows were opened, the inflow through the lower sidewall openings decreased, so that at about a 20 deg. opening of windward monitor openings there was no inflow through the lower sidewall openings. After opening the windward monitor openings more than 20 deg. the side-wall openings were outflow openings, indicating a cross flow across the monitor, independent of its shape, that clogged up the leeward monitor openings and made them ineffective for pulling air from the zone of occupation, thus jeopardising the airation.

Almost everyone is familiar with the convection currents induced by the rise of warm and the fall of cold air. The potentiality of this temperature difference for creating an air current is called the motive head—comparable with a head of steam or a head of water.

The motive head, due to temperature difference, producing flow, is directly pro-

portional to both the difference in temperature and the vertical distance between inlet and outlet openings, and depends practically upon nothing else. The head, in feet of air, is determined by multiplying the vertical distance between upper and lower openings in feet by the difference in temperature between inside and outside air, and dividing by the average absolute temperature.

The velocity of flow due to temperature difference varies with the square root of the head, while the volume of air passing through an opening varies directly with the velocity, directly with the area of the opening and directly with the constant or coefficient that depends on the character of the opening. By experimentation coefficients for a great many types of windows and different degrees of open-

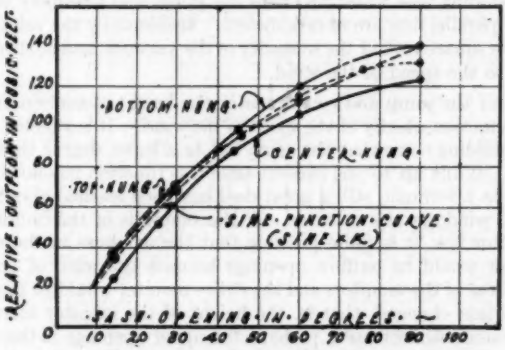


FIG. 5. CURVES ILLUSTRATING FLOW OF AIR THROUGH VARIOUS TYPES OF PIVOTED WINDOW OPENINGS

ings of such windows have been determined, and a great many of them have been checked in field surveys. For instance, the constant is very nearly 0.60 for a horizontally pivoted window open 90 deg.

The curves in Fig. 4 show the coefficients of resistance of various degrees of openings for three types of pivoted steel windows, plotted to show their relationship with the sine function curve. For all practical purposes it can be said that the coefficients of resistance vary with the sine of the angle of the openings.

In order that there may be a flow of air due to temperature difference only there must be a difference in height between inlet and outlet openings, and our tests confirm this. While this fact is manifestly true many building designs are found that depend for ventilation on getting air in at certain openings, and out at other openings at just about the same level.

To compute the flow due to temperature difference, when inflow and outflow openings are of unequal area or resistance, there has been developed the important conception of the neutral zone. If air will flow in at certain openings because atmospheric pressure is greater on the outside, and out at certain other openings because atmospheric pressure is less, there is a point of equal atmospheric pressure somewhere between where the air will neither flow in nor out of an opening so

located. This explains why high outflow openings and low inflow openings are more effective than openings situated near mid height. The location of the neutral zone varies with the size and resistance of the inflow and outflow openings and its location is found in somewhat the way as the center of gravity of a section is obtained. Likewise the position of the neutral zone is used in computing flow in about the same way as we use the location of the center of gravity of a section in computing its moment of inertia. This is covered by Prof. J. E. Emswiler in a paper The Neutral Zone in Ventilation published in the January, 1926 issue of the JOURNAL OF THE A.S.H.&V.E., and is also quite adequately covered in *Bulletin* No. 3 issued by the Department of Engineering Research of the University of Michigan with Emswiler and Randall, the authors.

Temperature Difference and the Wind

To compute the motive head causing air flow in and out of a building due to the combined motive forces of the wind and the temperature difference it is necessary to combine the heads due to:

1. The pressure effect of the wind
2. The suction or pulling effect of the wind
3. The head due to temperature difference.

Computing the resultant flow would be simplified if a summation of the flows,

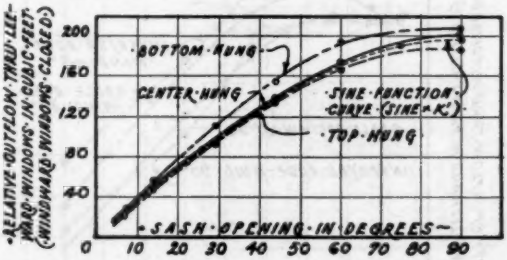


FIG. 6. CURVES INDICATING FLOW FOR DIFFERENT DEGREES OF OPENINGS OF DIFFERENT TYPES OF PIVOTED WINDOWS

due to each of the above forces, could be made, but this cannot be done since heads must be added and not flows. Assuming that the temperature difference alone is causing flow and then the effect of the wind is superimposed upon it, the increased flow immediately causes a drop in inside temperature, thus decreasing the flow due to temperature difference. On the average the flow due to wind and temperature difference acting together is about 70 per cent of the addition of the flows of these forces acting alone.

In the summer time advantage can usually be taken of the motive force of the wind and large volumes of air can be brought in to reduce the temperature difference, but the effective head due to temperature difference becomes materially less. In the winter the story is different, and in general the head created by tem-

perature difference would be the chief motive force, since the inside air of an industrial building is considerably warmer than the outside air. This condition gives a head sufficient for all except the most extraordinary cases. Under winter conditions the pressure effect of the wind forcing air into a building would usually create too great a cooling effect and perhaps cause objectionable drafts.

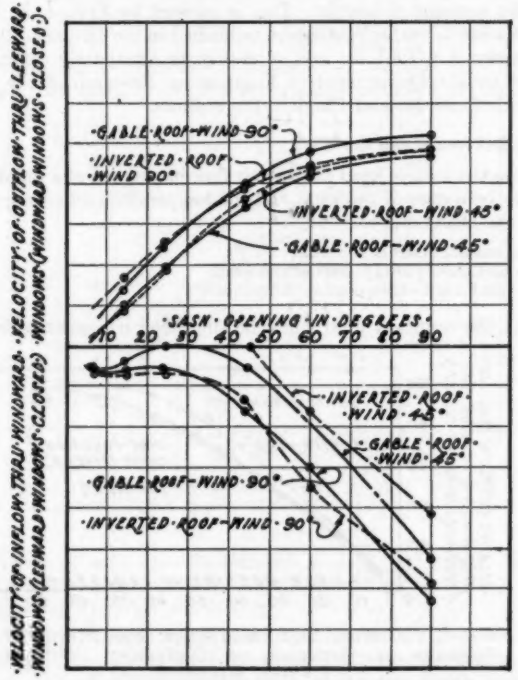

VELOCITY OF INFLOW THRU WINDOWS
VELOCITY OF OUTFLOW THRU LEEWARD WINDOWS (WINDOWS CLOSED)
GABLE ROOF-WIND 90°
INVERTED ROOF-WIND 90°
INVERTED ROOF-WIND 45°
GABLE ROOF-WIND 45°
SASH OPENING IN DEGREES
10 20 30 40 50 60 70 80 90
INVERTED ROOF-WIND 45°
GABLE ROOF-WIND 45°
GABLE ROOF-WIND 90°
INVERTED ROOF-WIND 90°

FIG. 7. COMPARISON OF FLOW THROUGH EQUAL AREAS OF WINDOWS IN A GABLE ROOF AND INVERTED ROOF MONITOR

The greatest flow in the summer time will probably occur when all windows are open. The most effective flow, that is, through the breathing zone, will usually occur when all except the high window openings on the windward side are open. In the winter time, the best airating conditions will occur when only the low openings on the windward or leeward side and the high openings in the leeward side are opened. If opening the low sidewall windows should cause objectionable drafts or excessive cooling, then higher sidewall openings should be used for inflow openings. This will diminish the too great cooling effect that might occur with low incoming air, at the same time the decreased height between inlet and outlet open-

ings will not decrease the head to such an extent that the air flow will not be sufficient.

Factors Which Control the Flow of Air

Since windows are the medium usually used for airation or natural ventilation, it is quite natural that research should cover the influence of the different types

TABLE 2. TEST RESULTS INDICATING THAT FLOW OF AIR DUE TO TEMPERATURE DIFFERENCE IS NOT AFFECTED BY FORM OF MONITOR ROOF

TYPE OF ROOF	ANEMOMETER READINGS		
	TALL MODEL		SHORT MODEL
	1ST TEST	2ND TEST	
HIGH GABLE	240	232	165
LOW GABLE	238	232	164
FLAT	238	228	165
SHALLOW INVERTED	237	225	163
DEEP INVERTED	240	228	162

TABLE 3. MEASURED EXHAUST VELOCITIES THROUGH ROOF VENTILATORS AND MONITOR OPENINGS IN ADJACENT LOCATIONS FOR VARIOUS COMBINATIONS OF WIND AND TEMPERATURE DIFFERENCE

TEST NO.	AVERAGE EXHAUST VELOCITY IN FT./MIN. THRU		TEST NO.	AVERAGE EXHAUST VELOCITY IN FT./MIN. THRU	
	ROOF VENTILATOR	MONITOR WINDOWS		ROOF VENTILATOR	MONITOR WINDOWS
1	50	48	6	98	85
2	58	62	7	960	824
3	68	45	8	872	878
4	92	88	9	526	830
5	85	88	10	435	422

of windows on the flow of air. From many tests and surveys two general conclusions have been determined:

First: The flow of air through a window opening does not depend on the type of window used. There is little to choose, for the same degree of opening, between a window with a movable portion that is top-hung, center pivoted, bottom-hung, etc., and no type has any mysterious and predominant advantage over any other, and this is shown by the curves of Fig. 5. These curves are taken from the tests of the flow due to temperature difference. The findings would not check the statement seen by the author with reference to top-hung continuous sash, that it "facilitates the removal of heated air instead of impeding it as is done by pivoted sash in roof openings."

Second: The flow of air through a window opening varies with the area of the opening. For a pivoted window opening the flow varies with the angle of the opening, or, rather, the sine of that angle, to be strictly accurate. In other words, the first 15 deg. of opening gives 25 per cent of the total flow, the second 15 deg. 22 per cent, the third 15 deg. 19 per cent, the fourth 15 deg. 16 per cent, the fifth 15 deg. 12 per cent, and the last 15 deg. 6 per cent. This is illustrated by the curves of Fig. 6. This shatters one of the pet ideas formerly expounded by the company with which the author is

associated that the vertical height of the opening of a pivoted window was the measure of the flow. There is just this that should be recognized with pivoted windows; the operating devices usually limit the opening of top-hung windows to about 45 deg., whereas center pivoted windows can normally be opened all the way up to 90 deg.

The size of the inlet and outlet openings should be about equal for the greatest flow per unit area of combined inlet and outlet area. There is an increased flow up to the point of outlet area being twice the inlet area and *vice versa*. Beyond that proportion there is correspondingly little to be gained and preponderance of size of outlet over inlet (or the reverse) is of relatively small value. Some of the most

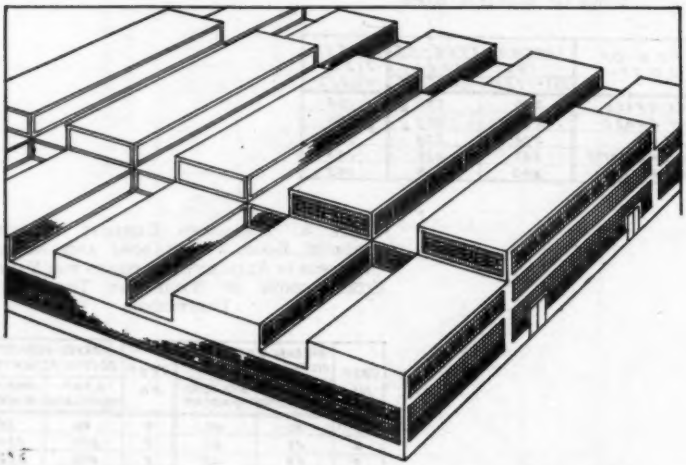


FIG. 8. DESIGN OF AN INDUSTRIAL BUILDING WITH EQUAL WINDOW-OPENING AREAS, PARALLEL AND PERPENDICULAR TO LONGITUDINAL AXIS

inefficient uses of opening areas have been found where this simple fundamental has been violated.

The shape of the roof, particularly that of the monitor roof, has little influence on the flow of air. There are such statements as "the roof slopes are designed to lead the air naturally to and through the outlets," but it has not been found that the air is so led. This is shown by Table 2 which covers tests of flow due to temperature difference during which were used roofs of various types, ranging from high gable to deep inverted. The author has read more than once that "the butterfly roof creates a vacuum." That may be true but the vacuum thus created is no more effective than that created by any other monitor roof of the same dimensions, the wind conditions remaining constant. In other words, certain forms of roofs that are put forth as cure-alls really depend on the size, orientation, height above the floor, etc., rather than on roof design itself and the form of the roof, as stated before, has little or no significance. This is shown by the curves, Fig. 7,

comparing the flow through equal areas of windows in a gable roof and inverted roof monitor. The flow is affected by the opening of the window and the direction of the wind, but the flow does not seem to be affected by the form of the roof. The curves are the results of tests on bottom-hung open-out windows.

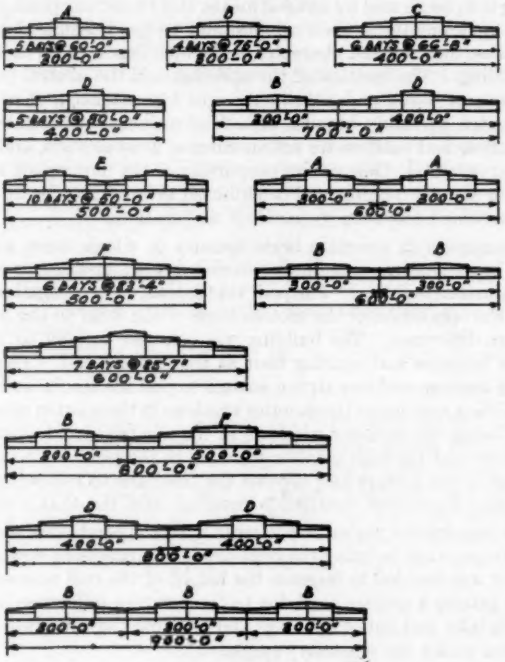


FIG. 9. TYPICAL CROSS SECTION THROUGH PROPOSED DESIGN SHOWING POSSIBLE BAY WIDTHS FOR VARIOUS WIDTHS OF BUILDING

The surveys taken indicate that louvers, roof ventilators, etc., have for their motive heads the same ventilating forces as do windows. In adjacent locations and under similar conditions, the velocity of air through a roof ventilator was about the same as that through a window opening, as is shown in Table 3. Apparently the fundamental requirement is a weather-protected opening, so designed, placed and controlled that the action of the wind is correctly used. Incidentally, it was found that a great many roof ventilators did not function because the damper was closed. Roof ventilators designed to revolve, that did not revolve, were often inflow openings The evidence would indicate that the efficiency of roof ventila-

tors dropped in proportion as they were dolled up with gew-gaws and fol-de-rol. Apparently the superiority complex of some manufacturers is not justified and the mystic haze about some devices seems, on investigation, to disappear.

General Principles for Airation

If a building is to be airated by natural means there must be openings and control, but buildings vary greatly in their adaptability to good design along these lines. The number, size, location and character of the openings is more or less individual with each building. The location of the openings and the control thereof is probably the paramount issue and usually receives less attention than the number, size and character, probably because of lack of authentic information along this line. Total inflow and outflow are not an index of good airation, and it was apparent in these surveys that often a large proportion of the moving air was short circuited across or along a monitor and contributed little or nothing to the effective airation and in some cases even jeopardized the airation.

This was illustrated in a certain brass foundry in which there was a malady, the so-called brass shakes, sometimes associated with inadequate ventilation in this type of industrial building. The poor ventilation, on investigation, was quickly attributed to the opposition of the motive force of the wind to the head produced by temperature difference. The building was oriented parallel to the prevailing wind with the furnaces and pouring floor at the leeward end. The jump of the wind created a vacuum and was strong enough to pull the smoke and gases lengthwise of the building and out at the monitor windows in the suction area at the windward end. Closing the monitor windows in the windward end, opening some low sidewall windows and the high monitor windows in the leeward end took the force of the wind out of the picture and allowed the head due to temperature difference to do the work. Successful ventilation resulted, and the shakes disappeared.

On the new foundry for the same company with the conditions about the same, it was found impractical to bring the heat-producing processes down to the windward end, so it was decided to increase the height of the roof above the heat processes, thereby getting a greater head due to temperature difference by the greater height between inlet and outlet openings and bringing the wind into action by the vacuum created under the secondary jump.

Before laying down the general principles which are at hand, permit me to say that there is a deep appreciation of the limitations of the suggestions and it is not expected that they will be followed in all cases. These suggestions are offered simply for what they may be worth, as a possible contribution to good construction and engineering.

The general principles would be:

1. Equal window openings, parallel and perpendicular to the longitudinal axis of the building.
2. Windows higher from the floor as they approach the center longitudinal axis. It may be desirable on account of the width of the building to have more than one axis.

The illustration, Fig. 8, will give an idea of about what is recommended and Fig. 9 gives typical column spacing and aisle widths for widths of buildings from 300 to 900 ft. Buildings more or less than this width could follow similarly.

In general the discussion is restricted to the principles laid down and their application on this type of building to the airation. It might be mentioned, however, that the problems presented in the daylighting of buildings can be well taken care of in the design and that proper fenestration will give wonderful results in the intensity and uniformity of the daylighting. The design will, in a wide range of cases, take care of the production and handling of materials. The construction costs have been checked by a large and well-known firm of structural engineers and in their opinion the design is economical.

What will be gained in this and similar designs by the application of the principles laid down are:

1. There will always be openings, in the lee or jump of the wind, regardless of its direction, which can be opened for outflow and always windows which are subjected to the pressure effect of the wind which can be used for inflow openings.
2. Air can be brought in at almost any desired point, using the pressure effect of the wind, carried through the zone of occupation and out at other convenient points, giving an actual and controlled airation.
3. The design lends itself to purely local control of the airation at certain points, as well as mass control covering large floor areas.
4. The design lends itself to a wide range of the air movement, ranging from relatively small to extremely large amounts, since the window opening area can be varied within wide limits.
5. The motive force of the wind and the head due to temperature difference can be coordinated for effective airation.

The conservation of the human element is a fertile field in the economics of industry. It is now quite generally accepted that those things which promote the general welfare and protect the health, will favorably influence the morale, add to the satisfaction of employees, and in general increase their efficiency. It, therefore, seems feasible, since all the evidence to date would indicate that efficient ventilation fits in this picture very well, that there be incorporated in the design of industrial building adequate and correctly controlled airation.

APPENDIX

Methods of Test

The research on airation, on which the conclusions are given extended over a period of three years. The program was carried out on the following plan:

1. Review of all information available on natural ventilation written in English and German.
2. Model tests.
3. Field surveys.
4. Co-relation of model tests and field surveys.

Review of Available Information

As indicated, the first approach to the problem was a search of all available information. Much of the "art" was read. A perusal of the extracts shows that little information on the subject had been written, and most of the real information was obtained from papers by English authors. A large proportion of the state-

FIG. 10. A MODEL FACTORY BUILDING USED IN TEST

ments made seemed inaccurate on their face and some were so highly colored as to create lack of confidence. A number of things said by one author were often repeated by others on the assumption that they were true, probably because they seemed plausible. It, therefore, seemed essential to disregard, at least temporarily, practically all that had been written and start at the bottom.

Model Tests

The apparatus used for making wind tests on the model, Fig. 10, is shown in Fig. 11. A 75 h.p. Sirocco fan delivered air through a wind duct or tunnel, the

FIG. 11. SKETCH OF SET-UP FOR WIND TESTS ON MODELS

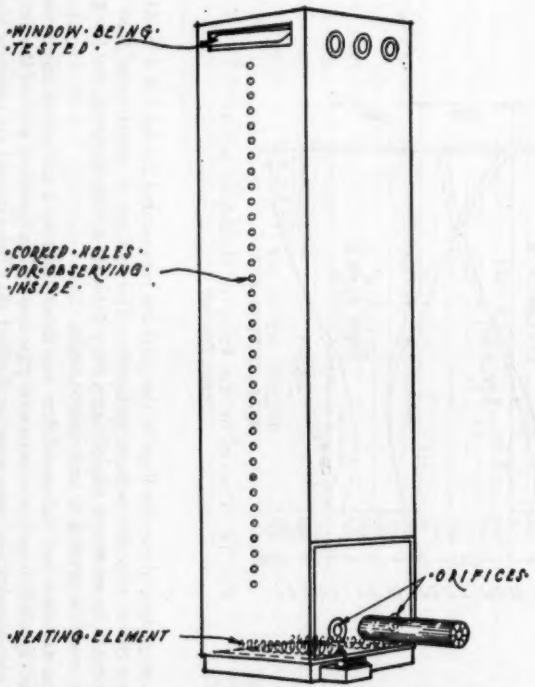


FIG. 12. MODEL FOR MEASURING FLOW DUE TO THE HEAD CREATED BY TEMPERATURE DIFFERENCE

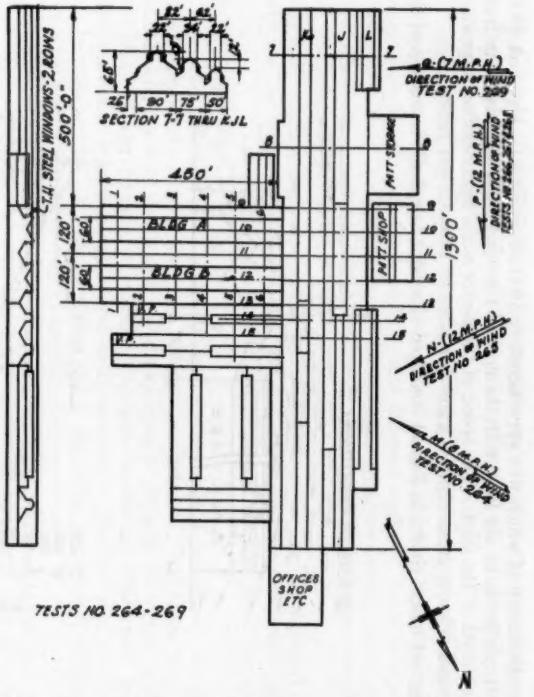


FIG. 13. PLAN OF AN INDUSTRIAL PLANT ON WHICH A SERIES OF FIELD SURVEYS WERE MADE

outlet dimension of which was approximately 10 ft. wide by 3 ft. high. A 10 ft. x 15 ft. platform, on the level with the floor of the wind duct, was placed in front of the mouth of the duct. The speed of the motor could be controlled to produce any wind velocity from about 2 miles per hour to 20 miles per hour.

The test model shown in Fig. 11 consisted of a tight box, built to scale, and the

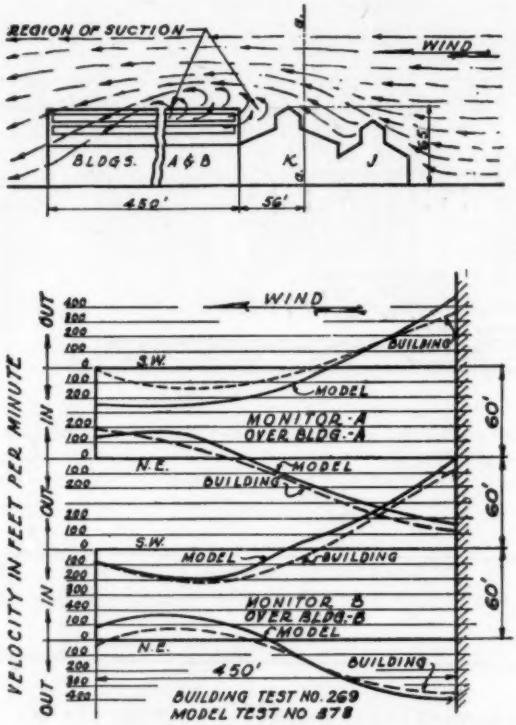


FIG. 14. CURVES OF AIR FLOW AS MEASURED DURING FIELD SURVEY

part projecting above the floor of the platform represented the roof of a building with a run of movable sash on each side. The roof was so constructed that the slope could be set at any angle from a steep gable, to a deep inverted, and the windows could be opened to any desired angle.

The direction and volume of flow was determined by a calibrated anemometer placed in a 3 ft. length of sheet metal pipe inserted in the lower part of the model. The anemometer and pipe were so shielded that the external air currents would

have no effect upon the action of the instrument. The construction of the model and platform permitted the model to be oriented so that the wind could blow over it at any desired angle.

This particular set-up was not used so much to determine actual volumes of air passing through the model as it was to determine the effect of various types of monitor roofs, different wind velocities and different angles of the wind upon the direction of flow through the model for different window-opening combinations. The other set-ups were similar to the above, the details of which were determined by the nature of the test.

A wall board box 4 ft. square and 20 ft. high, shown in Fig. 12, was used to determine the coefficients of resistance for different openings of different types of windows. This model was also used to obtain data of the flow of air due to temperature difference.

A window opening was cut in the wall near the top. On the same level, on another side of the box, there were three 6 in. holes cut in the wall. Over these holes could be attached pieces of cardboard containing holes of $5^3/_{16}$ in. diameter, (a standard orifice having the same resistance as the anemometer and pipe unit), or other pieces containing holes equal in area to three-quarters, one-half and one-quarter of the standard orifice. Similar holes and a like set of card-board orifices were provided at the bottom of the tall model.

An electric heater, located in the bottom of the model, warmed the air and caused flow. One-inch holes, stopped with corks, were located up one side of the model and by means of these, and a smoke apparatus, the position of the neutral zone (see Prof. J. E. Emswiler's paper, The Neutral Zone in Ventilation, A.S.H.&V.E. JOURNAL of January, 1926) could be established.

In testing the window was first closed tight. A certain combination of orifices was then arranged, exactly alike at top and bottom of model. The neutral zone was then located. Immediately, the upper orifices were covered, and the window opened to such a degree that the neutral zone was re-established in the same position as that occupied when the orifices were in use instead of the window. The angle of opening of the sash was then observed and recorded, in connection with the orifice combination for that setting.

It is seen that the method employed consists in comparing directly an unknown resistance with a standard resistance, using the neutral zone as a sensitive means of indicating when equilibrium between the known and unknown has been established. It involves no observation except that of determination of the neutral zone, and a reading of the angle of setting of the sash. The accuracy of the method is very good—better in fact than is the accuracy of our knowledge of the Standard Resistance method.

Field Surveys

The results of the original model tests lacked the convincing element of verification on actual buildings. Exploration of actual buildings permitted study of the combined effect of temperature difference and the wind, and for this type of study the problem of scale on models is almost unsurmountable. Therefore, serious studies were made extending over long periods of time, at typical industrial plants. (See Fig. 13.) Usually the testing party consisted of five men, the tests

were run for several consecutive days, and the general plan was to put down the general conditions of the wind and temperature difference and to measure the flow of air at such a number and location of test stations as would actually tell what was really happening in the airation of the building or group of buildings.

Co-relation of Model Tests and Field Surveys

The results of tests on actual buildings have been analyzed and have been compared with the application of such theories and general experience as had been acquired on model tests. In many cases after tests on buildings, models of the buildings have been constructed in some completeness of detail and tested in the laboratory for the express purpose of finding whether or not the use of models was justified in predetermining the airating characteristics of full-size structures.

Brief reference will be made to but one of the many examples of the co-relation of field surveys and model tests. Fig. 13 is a floor plan of a large industrial plant specializing on large steel castings. The cross lines, 1–1, 2–2, etc., indicate the lines of the test stations. The direction and velocity of the wind during the six field surveys is shown.

Fig. 14 is a cross section through buildings *J*, *K* and *A* or *B*, and shows the general direction of the wind perpendicular to buildings *K* and *J*, and parallel to buildings *A* and *B*. The height of buildings *J* and *K* was such as to cause a jump of the wind over the windward end of buildings *A* and *B* and therefore create a suction area at the windward end. In Fig. 14 are also shown the curves of the velocity of flow through the monitor windows as measured during the field surveys and as measured on the model of the buildings, Fig 10. Such checks as the above, it is believed, are close enough for all practical purposes and would justify the conclusions which were arrived at by the use of models, which could not have been obtained by any other practical method.

DISCUSSION

L. A. HARDING (WRITTEN): This paper is the most complete analysis of the subject that has thus far appeared in any American publication.

The author and his company deserve the thanks of all engineers interested in industrial plant design and operation for the thorough and scientific manner in which they have covered the subject.

The conclusions drawn from the data collected from tests extending over a period of several years are of more than passing interest. The paper should be read and digested by engineers and architects who specialize in the industrial field, in order that they may frequently better serve the interests of their clients.

There are many points in reference to the theory of airation brought out in this paper which apparently were not in the past very well understood by engineers.

The writer was very much interested in the statements made in reference to the effect of roof shapes on airation and particularly to the inverted gable type. This type of roof is not only more expensive to construct from a structural, sash and glazing standpoint but increases the cost due to the inside leaders and under the floor cast-iron sewer pipe required, as compared with the straight side monitor type of roof construction.

With many processes of manufacture, the airation of the building is of secondary importance, whereas daylight illumination is of considerable importance.

If we are able to design the building so that when properly daylighted the airation problem is at the same time solved in a satisfactory manner without additional cost, then we have accomplished something very much worth while for the owner.

Such a design is shown by Fig. 8 which it is claimed, by the author, complies with the requirements for both efficient daylighting and good airation regardless of the direction of the wind, when the window ventilators are properly operated.

The longitudinal bay spacing of the building is not stated. The writer would assume this to be approximately 20 ft. for an economical design.

An outline drawing of the structural design showing both longitudinal and transverse sections for the design shown by Fig. 8 would, I believe, give a little clearer understanding of the requirements to be met in respect to the structural features involved.

ANDREW VOGEL (WRITTEN): The paper presented by Mr. Randall is of particular interest because of its extremely wide application and also because it upsets one of the fundamental principles of industrial plant design. Heretofore it has been the custom in preparing a general plant layout for a large industrial plant to consider the topography and the climatic conditions with reference to temperature, humidity, rainfall and prevailing winds. These items will not be changed, but when considering prevailing winds we will no longer think in terms of placing the longitudinal axes of the various buildings parallel to the prevailing winds, but we will be able to place the buildings at right angles to the prevailing winds or at any angle desired in order to get better plant layout, because we will know just how the wind will act with reference to the plant layout itself.

Briefly, then, Mr. Randall has given us basic information for the natural ventilation of industrial plants. Those of you who have been accustomed to preparing general plant layouts know that it has been necessary to place the cleaner operations on the windward side and the dirtier operations on the leeward side. This practice, of course, will be continued, but it will be continued with a wider knowledge of how to handle disagreeable fumes and smoke from the dirty operations of the industrial plant.

It has a still wider application and that is with respect to city planning. City planning is relatively a new science in this country, although relatively old in Europe. You, of course, know, who have studied it that the city plan of New York is fundamentally wrong both from the standpoint of natural lighting and natural ventilation. If you will refer to the paper, particularly the chart on page twelve, you will note that the prevailing winds in New York City do not properly ventilate the multitude of crosstown streets.

In the summer season winds are of the most importance in industrial plant design, but, of course, winter winds must also be considered. I am going to be particularly brief as the hour is late and therefore will not discuss these items in detail, but I am prompted to say that future studies on this subject will bring out further information which will be of value not only in the natural ventilation of our industrial plants, but also to throw more light on the heating problems in the large

buildings we are now accustomed to use. All of us have had difficulty in obtaining uniform heating in large industrial plants. Most of the trouble has been due to natural ventilation currents going on all the time which we did not know anything about or only had vague knowledge regarding them. With more information it will be possible to plan the heating to better advantage.

The Illuminating Engineering Society has devoted, for the past two or three years, an entire session to the natural lighting of buildings and has already obtained enough information so that we have established rules as to the approximate areas and percentages of glass required for satisfactory natural lighting of buildings. We have also found that the testing of models of natural lighting showed exactly the conditions which would occur in industrial plants.

Now, then, with respect to the natural ventilation of buildings, I am pleading for a wider study by all of you so that you will be able to correlate model tests with field tests and apply them both in the design of future buildings. I had prior knowledge of the work that Mr. Randall was carrying on so that I was able to use some of the data in the preparation of plans for a large industrial building now in process of construction, and not only the principles of natural ventilation but also those of natural lighting were used.

It is a very great pleasure for me to express my appreciation of the splendid work that he has done and I do hope that more of you will enter this field; so that the forces of nature will be more thoroughly studied with respect to natural ventilation in order that we may be able to utilize the prevailing winds to ventilate not only our industrial plants but also our cities.

PROF. J. E. EMSWILER: I will only say a word, about the use of models for determining data such as this paper is based upon. A model is particularly suited for examining the effect of the wind, because the intensities of the pressures and suctions are produced in full scale. It doesn't make any difference whether the object that is placed in the path of the wind is only a few feet in dimension or whether it is a few hundred feet, the intensity of the pressure and suction is just the same; so that the model, as I say, is an eminently suitable way of examining the influence of the wind. It gives control of all the variables and brings everything within the range of vision and perception. Of course, in connection with the temperature difference, that is an entirely different story, because temperature difference is a direct function of height. In a model we can secure, of course, the temperatures that are suitable, but the forces that are produced would be only in proportion to the height. Therefore, we had to resort to the unbalanced design of the model, the tall, narrow affair, in order to verify experimentally some of the things that we wanted to know. Fortunately, however, the forces resulting from temperature differences are easily or readily calculable from the laws of physics, and it was only necessary to verify these, and to determine the coefficient of resistances of operation in order to calculate flow.

MR. RANDALL: While I have tried to be conservative and accurate in all the statements which have been made in this paper, I was in hopes that the discussion would include some serious objections. I can usually answer objections or elaborate on the points made, but I am at a loss to know how to reply to the discussion presented which seems to be chiefly commendation. Needless to say, however, both Professor Emswiler and myself appreciate some of the nice things which have been said.

No. 794

DAIRY STABLE VENTILATION

By F. L. Fairbanks,[1] Ithaca, N. Y.

NON-MEMBER

THE subject of dairy stable ventilation has received considerable attention in New York State during the past few years and the author will discuss briefly the situation as it was understood and practiced for many years and possibly, in some instances, is today, and then describe some studies of the problem, pointing out important factors determined and describe the discovery of the effect of internal air movement on the ventilation problem.

First of all, there is the King theory of ventilation, having as its principal objective the maintenance of a certain per cent purity of air in the stable, the hourly flow for this purpose being computed as 3545 cu. ft. per head of stock of 1000 lb. weight.

A great deal of work has been done about this assumption and resulting from it are three distinct types of systems, the King, the Rutherford, and the Modified Rutherford. All three of these systems had their advocates and no one was able to prove one superior to the other, for the air usually went out of the flues at the proper rate in all cases.

The milk ordinance boards specified *adequate ventilation* for dairy stables as all the medical men agreed that fresh air was desirable. At this point, milk regulations began to require ceiling the inside of dairy stables to make the walls smooth and tight for sanitary reasons.

With the remodeling of dairy stables to suit the milk ordinance rules, a big group of dairymen supplying milk to cities found that the labor and material that they had expended in improving their stables was likely to be all lost because, instead of having a stable wall which would allow moist air to pass through it more or less freely, they now had a tight wall which prevented the escape of the stable moisture. The result was that moisture collected on the ceiling and walls, window sills were flooded with water, windows swelled either open or shut, doors warped, the ceiling in some cases swelled and buckled, and, if the dairyman attempted to relieve the conditions by opening the hay shutes, the hay around the shute became wet and rotted and the underside of the roof became coated with frost which, on the next sunny day, melted and soaked the roof timbers full of water.

Thus, like many other subjects, the factor that had been considered as all im-

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[1] New York State College of Agriculture, Cornell University, Ithaca, New York.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

portant (the purity of the air in the stable) became submerged in the problem of moisture removal.

At this stage then, when commercial and home-made systems of ventilation were in operation in dairy stables and no one was satisfied and everybody was arguing about the subject and the moisture problem was getting worse in both ventilated and unventilated stables, and the commercial companies were sitting tight on

FIG. 1. AIR MOVEMENT STUDY—SINGLE GLASS WINDOW IN A STEAM HEATED ROOM

their own pet theories, it was at this point that Prof. A. M. Goodman and the author, feeling like the "fools that rush in where angels fear to tread," took over the study of what seemed to be an important agricultural engineering problem—that is, the preservation of the structure of the dairy stable and barn by the removal of excess moisture from the dairy stable.

Other factors also were in mind which were not so easy of solution or rather measurement, such as improvement in the health of the stock in connection with the T. B. campaign of the State, more efficient working conditions for the dairyman, and the installation of a system of ventilation which would relieve the dairyman of the constant manipulation of the doors, windows or flues to maintain reasonably uniform temperature, humidity and air conditions in the stable.

The first step was, therefore, a survey of the literature. This did not enlighten us much. Conferences were then held with the engineers of companies making ventilation systems for dairy stables. These conferences were interesting but not instructive.

There remained two courses of action, one to build an experimental stable and equip it with stock, etc., for test, the other to make tests in existing farm dairy stables. The latter was the only course open at the time, so a survey of the state was made and representative systems of the various types both commercial and home-made in the different dairy sections of the state were selected for test.

The ventilation of dairy stables is most difficult during the midwinter months

FIG. 2. AIR ENTERING A STABLE AS SHOWN BY THE VENTILATION INDICATOR PLACED IN THE INTAKE UPPER RIGHT

when extremes of temperature, wind and humidity occur. It was, therefore, decided to make the tests during the months of January and February.

There were no very definite formulae for determining the flue area for a stable, but all seemed to hinge about the King theory, and, in general, the formula developed by J. L. Strahan[2] of the Louden Machinery Co. for a 20 deg. difference in temperature seemed to fit fairly well, *i. e.*, $A = \frac{170N}{\sqrt{H}}$

in which A = total area of flues in square inches.
N = number of cow units, stable capacity.

[2] J. L. Strahan, "Design of Outtake Flues for Stable Ventilation," Transactions A.S.of A.E., Vol. XV, 1921

H = difference in elevation in ft. between the point where fresh air enters stable and point where foul air leaves outtake flue.

The factors that were thought to be important to the proper functioning of a ventilation system were:

1. Number of cubic feet of air space in stable per head of stock
2. Insulation of the stable
3. Height of flue
4. Area of flue.

Therefore, in the tests made, a check on the measurements and construction of the stable and system was taken in each case before starting the actual test.

In making the tests, it was necessary for Prof. Goodman and the author to work

FIG. 3. AIR MOVEMENT ADJACENT TO AN OUTTAKE—THE VENTILATION INDICATOR ON THE FLOOR WITHIN TWO FEET OF AN OUTTAKE

in 12-hour shifts each, the shift being made at 12 noon and 12 midnight. Each man was on duty constantly during his shift except for meals.

Recording instruments were used in the stable and out-of-doors for temperature and relative humidity measurements. The readings of out-door conditions were:

1. Weather
2. Temperature
3. Relative humidity
4. Wind velocity at ridge of barn
5. Wind direction
6. Barometric pressure.

In the stable from 10 to 40 stations were selected at floor, ceiling and mid-points in the alleys and over the cows, for the reading of temperature and relative humidity. In addition the velocity of air through the intakes and outtakes was measured as well as the temperature at different points in the flues.

A start was made by taking readings every 3 hours but it was found that at times of weather changes things were happening in between readings for which no record was available.

Certain unexplained temperature and relative humidity changes were taking

FIG. 4. THE VENTILATION INDICATOR—THE APPARATUS DEVELOPED TO DETECT AND TRACE AIR MOVEMENTS WITHIN THE STABLE

place for which no explanation could be found. Then, too, condensation was occurring in certain parts of the stables for no apparent reason, some parts of the stables were comparatively free from odors, some stables, with the same air movement, so far as it could be measured, were noticeably more smelly than others.

The next step was to take continuous readings throughout weather changes. This gave the missing points on the curves; still we were in the dark as to why certain stable conditions persisted. There was something going on which could be measured, but for which there was no evidence as to the cause. A number of causes could be assumed, but that was not satisfactory for we could not be sure that our assumptions were correct.

The air flow for any type of system could be measured. Some systems were more

affected by out-door temperature changes than others. No very great difference in relative humidity for the different systems was noted, but some stables were more

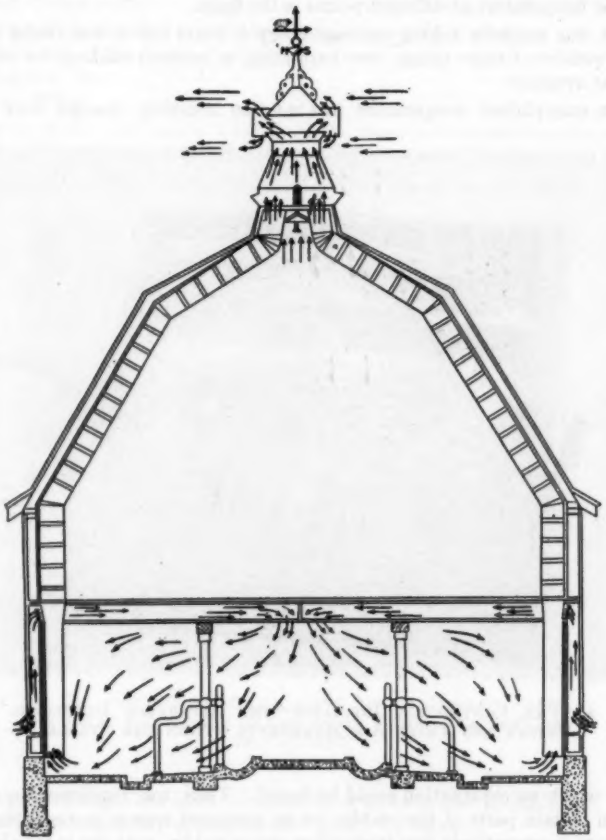

FIG. 5. INDICATING OLD THEORY OF AIR MOVEMENT—THE KING TYPE

smelly and wet than others. Why? That was a question to be answered. Therefore, a study of the air movement in the stables was started.

The outtakes behaved quite uniformly. The intakes were affected by the wind and type of opening into the stables.

The air movement within the stables could not be seen but it was felt that some-

thing must be going on there that was the cause of all these unexplained happenings. The usual two-bottle ammonium chloride smoker was used, but the stable air movement was so gentle that the heat from the observer's body affected the smoke

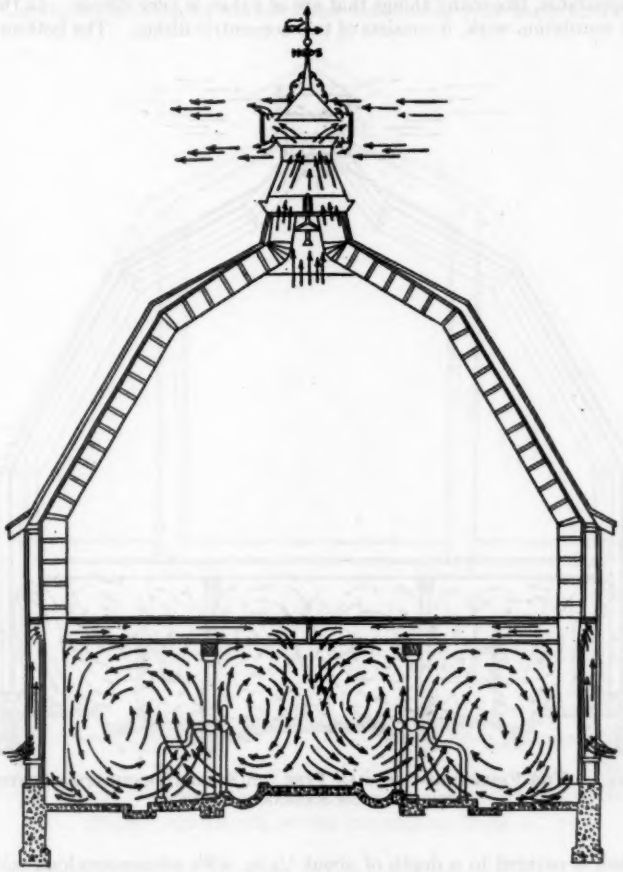

FIG. 6. ACTUAL AIR CIRCULATION AS DETERMINED BY VENTILATION INDICATOR

drift or caused eddies. Also, blowing the ammonium chloride out of the tubes gave an initial velocity to the smoke and, therefore, was not a true indicator.

Thus necessity, which is the mother of invention, caused us to look for some device for accurately detecting the air movement within the stables and the author

devised an apparatus which is called a Ventilation Indicator, Figs. 1, 2, 3 and 4, for the spontaneous generation of ammonium chloride vapor and with it several puzzling points have been cleared up.

The apparatus, like many things that are of value, is very simple. In the form used for ventilation work, it consists of two concentric dishes. The bottom of the

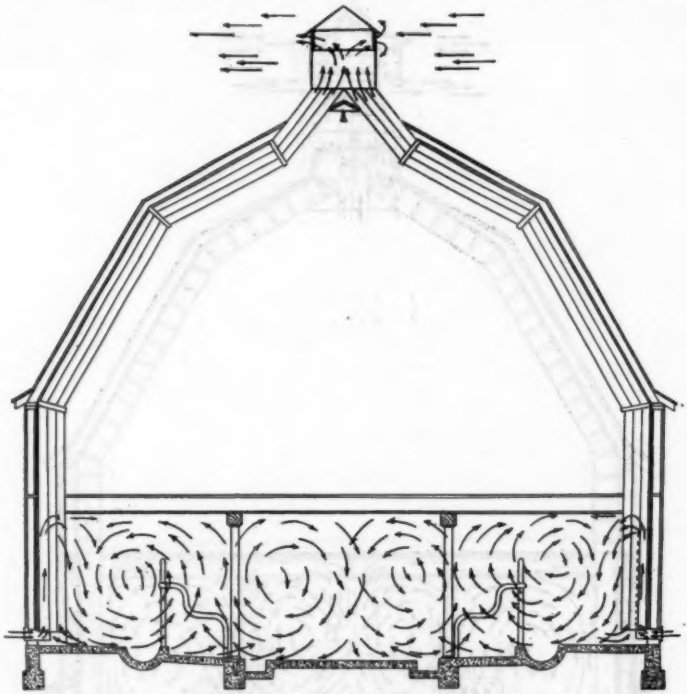

FIG. 7. THE FAIRBANKS-GOODMAN TYPE. A STABLE VENTILATION SYSTEM DESIGNED FROM RESEARCH RESULTS

larger dish is covered to a depth of about 1/8 in. with ammonium hydroxide, the bottom of the smaller dish is covered to the same depth with hydrochloric acid. The smaller dish is placed within the larger dish and the vapors from the two chemicals immediately combine to form the familiar ammonium chloride salt.

Through the cooperation of Eimer and Amend in this work, the complete apparatus in suitable carrying case with compartments for sling psychrometer and anemometer is available so as to provide complete equipment for air movement studies.

Now let us discuss what has been learned about the air movement in dairy stables.

The original theory, universally accepted, was that the fresh air must enter in front of the cows, that it passed by the cows' heads and bodies and should be taken out of the stable from behind the cows and that it was quite important that out-

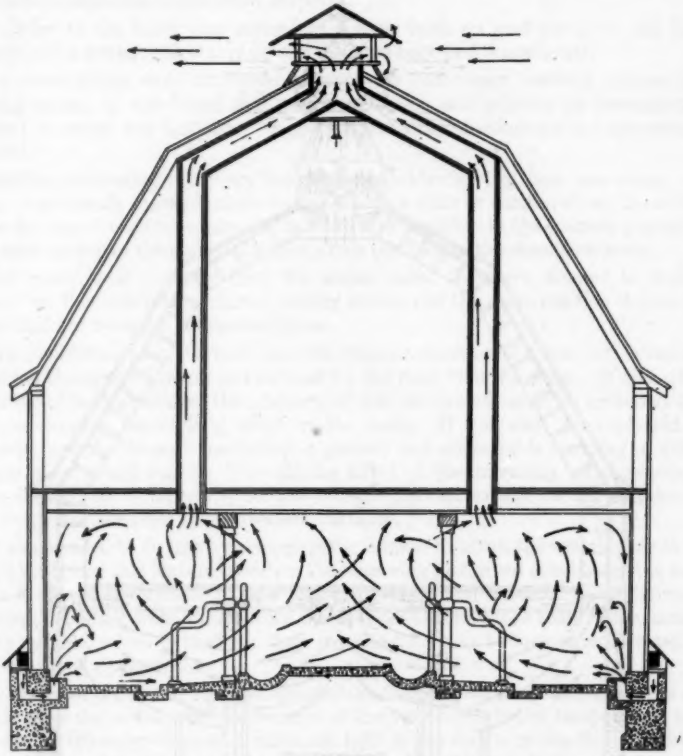

FIG. 8. AIR TRAVEL IN THE RUTHERFORD TYPE

take flues should be placed at certain specified intervals because the draft created would draw the air from the stable over a limited area only.

Thus in the past the air flow within the stable was represented as in Fig. 5 which indicates the natural draft system with floor outtakes and ceiling intakes as originally devised and illustrated by King.

But what was found by actual test in all stables having this type of system is shown in Fig. 6, a strong upward movement of air toward the ceiling about each row

of cows, a decided movement along the ceiling toward the wall, then down to the floor past the outtakes and back to the cows. A less decided but traceable movement occurred along the ceiling toward the center of the barn, down to the floor

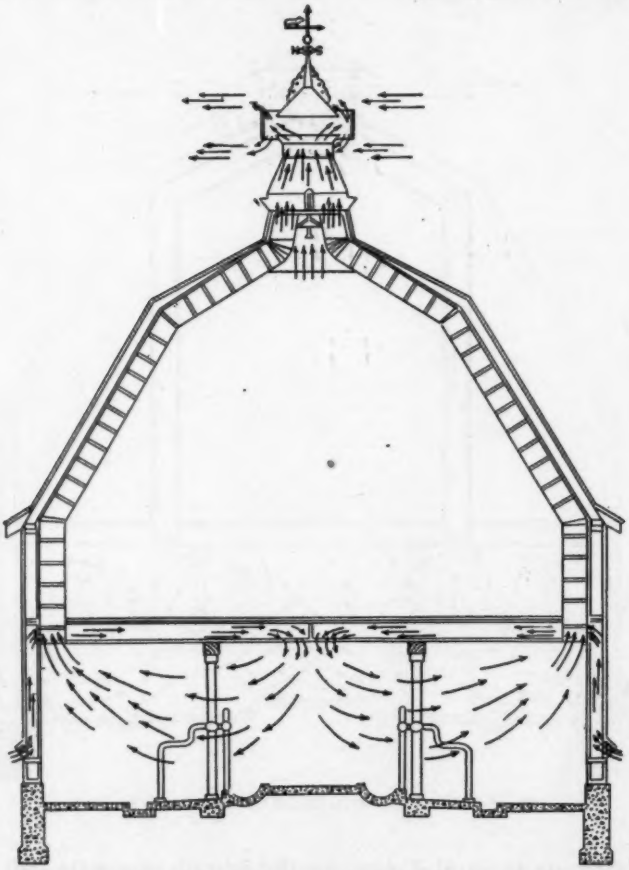

FIG. 9. AIR MOVEMENT IN THE MODIFIED RUTHERFORD SYSTEM

and back to the cows. This action was found regardless of whether the intake was at the center and the outtake at the wall or *vice versa*, although with the intake at the wall, the mixing action was more pronounced.

It was found also that if all drafts caused by leaks could be stopped, it was neces-

sary to get closer than 4 ft. to an outtake to detect any movement of the stable air to the outtake.

This seemed to indicate that the function of the outtake flue is not primarily to determine the direction of air currents by its location, but rather to act merely as an exhauster to lower the pressure in the stable leaving the factor of distribution wholly to intake location and convection currents.

This led to the belief that instead of moving fresh air past the cows, the fresh air was being mixed with stable air and the cows breathed this mixture.

As observations were continued to trace the convection currents causing this mixing action, it was found that when the action was positive no condensation seemed to occur, but that when the action was sluggish condensation was usually noticed.

Another interesting discovery was, that in stables having these convection currents most clearly marked, there was another air drift or current along the ceiling from the stanchion rows where the cows are close together to the sparsely populated box stall section of the stable and back along the floor to the stanchion rows.

The removal of moisture from the stable walls, therefore, seemed to depend mainly on this convection current mixing action and the more positive it was, the more uniform were the stable conditions.

The circulation past the walls was the downward sweep of a convection current in which the upward sweep was induced by the heat from the cows. With a given quantity of heat available, the intensity of this movement could be increased only by accentuating the chilling effect at the walls. If this were accomplished by reducing unduly the wall insulation, a general and undesirable lowering of stable temperature would result. The chilling effect of the incoming air, however, is unavoidable and it, therefore, became evident that advantage should be taken of this means to stimulate the convection currents.

It was decided to do this by arranging the intakes to admit the entering air at the stable walls and this feature based on the reasoning just given constitutes the most distinctive characteristics of the Fairbanks-Goodman system. The thorough diffusion resulting from this feature makes possible the other main characteristic of the system, which is that the floor outtake flues may be located as dictated by constructional convenience.

It had been proved to our own satisfaction that the floor outtake was more desirable than the ceiling outtake because of the very much better temperature control due to the large volume of warm air held in the stable by the floor outtakes, this volume acting as a heat reservoir which made sudden changes in temperature impossible.

The establishment of the importance of convection currents in stable ventilation would also eliminate the necessity of relating the design of the system to the direction in which the cattle face, with heads in or out, which, under the old theories, was considered a limiting factor.

With these facts and assumptions in mind, it was thought possible to design a system that would—

1. Completely and continuously mix the fresh incoming air with the stable air throughout the entire stable.

2. Prevent the condensation of moisture on the stable walls. These walls to be only moderately well insulated.

3. Remove foul odors and gases at such a rate that the air would be sweet and comfortable to breathe.

4. Maintain reasonably uniform temperature in the stable throughout the winter season.

5. Prevent freezing in the stable, without the use of artificial heat, while adequately ventilating the stable.

6. Function satisfactorily with a full stable or with 70 per cent or even 60 per cent capacity.

7. Allow the placing of the intakes on the side walls regardless of which way the cows face.

8. Permit location of the outtake flues wherever convenient to put them.

9. Function with the minimum of attention from the dairyman.

Such a system was built in a very ordinary 20-cow barn. Three walls of the stable were double boarded and ceiled while one wall next to the bay floor was of single boarding with roofing paper over it to stop the cracks. The wall insulation was thus below the average. There was only one outtake located at the point most convenient for construction and four intakes along two walls located to stimulate convection currents.

The operation of this system was most satisfactory and proved that the objectives previously stated were quite possible of attainment.

One might think that the complete mixing accomplished by the convection currents would saturate the stable with foul odors but it was found that with the proper flow of air through the stable and the high degree of air purity maintained, the air was not only free from unpleasant odors but was noticeably sweet with the odor of hay and pleasant to work in.

The Rutherford system with ceiling outtakes and floor intakes, which we have not had an opportunity to test as thoroughly as possible, is the other principal type of system and gives a diffusion of air somewhat as indicated by Fig. 8. It gives fair diffusion, but is subject to localized effects of outtake flue and when extreme cold periods of below zero temperatures occur the system has to be closed off, thereby destroying the ventilation effect.

The Modified Rutherford system using ceiling outtakes and ceiling intakes, Fig. 9, has been tested thoroughly and it has been found that there is a tendency for the incoming air to short circuit as shown by the arrows. Pockets of foul air are apt to occur and the system shows an extreme sensitiveness to weather changes.

With the ceiling outtake type and especially with the ceiling outtake and ceiling intake type of system, it is impossible to maintain uniform conditions throughout the stable and at low temperature periods the flow of air must be materially reduced and, at times, stopped to prevent freezing in the stable.

There are at present four types of systems of natural draft ventilation for dairy stables: the King, the Rutherford, the Modified Rutherford and the Fairbanks-Goodman type.

All of these systems are in use today and all of them are an improvement over no ventilation at all, but, like some other things, some of these systems are better than the others.

In concluding, please let it be emphasized that, from the studies of the air movement in stables, the essential factors in dairy-stable ventilation are found to be:

1. A heat reservoir should be maintained in the stable by means of floor outtakes if we are to secure temperature control.
2. Convection currents should be stimulated.
3. The positive action of these convection currents will give us complete mixing and diffusion of the fresh incoming air, uniform air conditions throughout the stable and will prevent the accumulation of condensed moisture on the walls or ceiling.
4. The stimulation of the convection currents is materially assisted by locating the intakes on the side walls.
5. Drafts are avoided by destroying the velocity of the incoming air as it enters the stable, thus making it fall of its own weight through the warm stable air.
6. By accomplishing complete mixing of the fresh air and stable air, we are able to locate the outtakes wherever it is most convenient to construct them, thus keeping the mow and stable free of obstructions.
7. No intake should be closer than 6 ft. to an outtake.
8. From 50 to 60 cu. ft. of air per minute per head of stock is sufficient to adequately ventilate and maintain a sweet dry stable.
9. These factors apply to both natural draft systems and mechanical draft systems such as electric fan outtake systems.
10. For the electric fan systems, properly designed and located intakes are as important as for the natural draft systems.

As a result of this work, the New York State College of Agriculture has published an Extension Bulletin, No. 151, which is intended to give the dairyman a better knowledge of the problems of ventilation of the dairy stable and to aid him in the selection of a system for his needs.

It is felt that much more work can be done in the way of determining the effect on the cattle of ventilated and unventilated conditions and in determining the exact amount of insulation needed.

What has been determined in regard to the movement of air in stables has been of great value to us and it is hoped that it may be of use in the solution of other ventilating problems.

DISCUSSION

PROF. A. C. WILLARD: The paper is most interesting. Prof. Fairbanks has shown us in our work at the University of Illinois in the study of circulation of air in experimental houses and experimental rooms a method for generating without initial velocity ammonium chloride fumes for the study of air currents. We are using the exact apparatus that Prof. Fairbanks has here, these double dishes of ammonium hydroxide, and by using them on a vertical standard, three sets of dishes, at floor, breathing line and ceiling height, we have discovered most unusual conditions of air flow, at these very low velocities, which exist both in indirectly heated rooms heated by warm air furnaces, and rooms which are heated by direct radiation with steam or hot water radiators.

One of the surprising things we have discovered in connection with the multiple arrangement on a vertical standard was the air flow between two rooms connected by an open door. In one room the amount of radiation or heat supplied was in excess of the requirements for that room and in the adjoining room the heating

requirements were not quite satisfied for that room. There was not only a circulation established between the two rooms through the doorway, but we have discovered there are three or even four different currents that flow through the doorway; one coming from the overheated room into the cooler one; one coming back across the floor line in the reverse direction with direct radiation and a third circulation at about the middle plane of the two rooms. This latter case was most pronounced in a warm air furnace installation. We never suspected this secondary circulation which goes on in the upper part of a room until we tried out these very delicate air drift indicators. We have tried a great many air drift indicators but practically all of them give some initial velocity to the jet. They require the presence of the operator in the immediate vicinity of the jet or the smoke fumes, the result being that the initial impetus given to the source of smoke vitiates the evidence that the jet seems to present.

I don't want to belittle the contribution Prof. Fairbanks has made in the field of barn ventilation, but this air drift indicator is one of the most important aids to the man making a study of air currents that has come to our attention in the field of heating rooms by direct or indirect systems. The investigator who overlooks the visual evidence which he can secure by the use of smoke fumes of some sort has overlooked a most important thing in his study of heating and ventilating problems. I want to thank Prof. Fairbanks for having prepared the paper, in as much as he showed us a method of arriving at results we never could have secured otherwise.

H. P. GANT: May I ask Prof. Willard in which direction the third air flow was found to go?

PROF. WILLARD: Usually in the exactly opposite direction from the one that is flowing on the floor in the case of a warm air furnace installation. We have found further that in a directly heated room with direct steam or hot water radiators placed at the window the air currents naturally rise to the ceiling, go across the ceiling in a thin layer to the inside wall, do not drop to the floor, but begin to come back toward the outside wall within a distance of 12 to 18 in. or less from the ceiling. In the upper part of the room, down to the height of the chairs, desks and other furniture, you will have a circulation that will be quite independent, possibly, from the circulation at the floor line.

No. 795

CORROSION IN STEAM HEATING SYSTEMS

By F. N. Speller,[1] Pittsburgh, Pa.

MEMBER

MUCH has been written on the deterioration of steam boilers, economizers and hot water supply piping, due to corrosion, but less on the deterioration of steam heating systems. Nevertheless, in some localities a considerable wastage of material in steam heating systems results from this cause—particularly is this noticeable in steam return lines. Chemical treatment and deaeration are now commonly applied to boiler water in power plants, but the need for such treatment in steam heating units has only been recognized recently in central heating plants.

In the construction of large buildings about 40 per cent of all the piping (except electric conduit) is used in heating systems. Steel or wrought iron pipe has been almost universally used for this purpose with variable results depending upon factors incidental to service and independent of the pipe material. Fortunately, serious corrosion of steam lines can be checked at relatively small expense and trouble.

The corrosion of steam heating systems is associated mainly with certain types of boiler feed water and, therefore, varies widely in different localities, depending upon the composition and quantity of non-condensable gases evolved with the steam. The harmful gases are oxygen and carbon dioxide. Sometimes serious corrosion is caused by abnormal leakage of air into the system.

The mechanism of corrosion is now quite generally understood and need not be described here in detail. Essentially the reaction involves the slow solution of iron in water to form ferrous hydroxide which, in the presence of free oxygen, forms the more insoluble ferric hydroxide commonly known as rust. A proportional amount of hydrogen is plated out, polarizing the metal and quickly stopping the solution of more iron. When oxygen is present it unites with the active hydrogen; or if an acid is present, molecular hydrogen is formed and evolved as a gas. In either case, when the restraining effect of the hydrogen film is removed, the high solution pressure of the metal causes more iron to enter solution and these reactions are repeated until either the iron or the free oxygen is exhausted. The chemical factors controlling corrosion in steam systems are, essentially, oxygen and carbon dioxide.

The free oxygen in natural waters does not vary materially under the same

[1] Metallurgical Engineer, National Tube Co., Pittsburgh, Pa.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

conditions in different localities, but the carbon dioxide which is loosely held in solution ranges from 5 to 100 p.p.m. or more. Carbon dioxide is usually present as the bicarbonate of calcium or magnesium. Therefore, waters which show a high degree of temporary (bicarbonate) hardness evolve more carbon dioxide when heated in a steam boiler than softer waters and therefore make a more corrosive steam. On the other hand, in plumbing systems, hard waters are usually much less corrosive toward piping than softer waters, due to the protective scale they deposit on the metal.

So, the problem of steam pipe corrosion includes three essential factors—

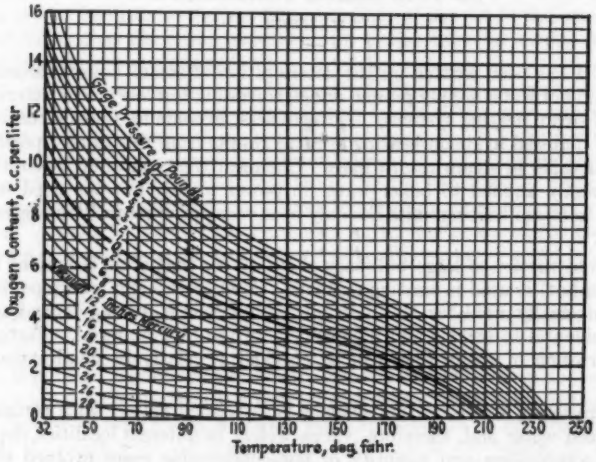

FIG. 1. SOLUBILITY OF OXYGEN IN WATER, ASSUMING SATURATION WITH WATER VAPOR

moisture, oxygen and carbon dioxide—the latter apparently being in most cases the chief accelerator of corrosion in return lines. Carbon dioxide at 60 deg. cent. (140 deg. fahr.) and atmospheric pressure is nearly one hundred times as soluble in water as oxygen, and is therefore readily taken up by the condensate. The solubility of these gases in water at various temperatures is indicated in Figs. 1 and 2. Furthermore, the ferrous bicarbonate formed will be decomposed in the boiler, releasing the CO_2 gas again so that a small amount of carbon dioxide may travel around the system repeatedly and, eventually, do considerable damage. The action of the acid in the absence of oxygen is relatively slight, so that every reasonable precaution should be taken to exclude air from the system, but, of course, this is not entirely practicable in steam heating systems especially when they operate under vacuum.

The difference in deterioration of steam systems of the same type in different localities is often due to the variable acidity of the condensate and this is a matter

that can be regulated to a large extent by the use of a suitable system of boiler water treatment. Steam return lines in New York City buildings using Catskill water, for example, suffer much less than similar systems in Los Angeles, where the water carries the same oxygen but over ten times the amount of active carbon dioxide as that present in New York water.

The influence of the type of design of the system on the rate of corrosion does not appear to be so important as other factors. Proper installation, however, is essential. As corrosion is proportional to the oxygen dissolved in the condensate

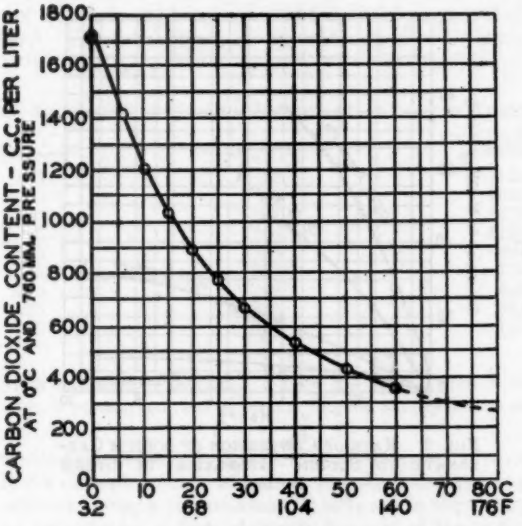

FIG. 2. SOLUBILITY OF CARBON DIOXIDE IN WATER

precautions should be taken, especially in systems operating below atmospheric pressure to make all joints air tight. Threaded joints may be made more secure by the addition of some zinc dust to the lubricant or threading dope. It always pays to keep threading dies in good condition. Smooth clean-cut threads can easily be made on steel pipe. Tight joints may be secured by welding.

Boiler water reactions control the acidity of the steam and as pointed out before, this factor will often account for the difference in durability between different systems. Acid steam is quite frequently produced from alkaline water. There are two common reactions by which carbon dioxide may be liberated from the water with the steam. The first involves the decomposition of bicarbonates, the half-bound CO_2 being driven off to some extent where the water is heated to 140 deg. fahr. Vacuum type deaerators operating at 180 deg. fahr. have been found to remove 35 per cent of the half-bound CO_2 from bicarbonates of calcium and mag-

nesium and as such apparatus will at the same time remove the free oxygen, deaerated water is very desirable for feeding a steam heating boiler. In systems where the hot condensate is returned to the boiler any oxygen which has been picked up may be removed by passing the condensate, with any make-up required, through an iron filter. This will protect the boiler and the steam system to a large extent, or the condensate from the system may be discharged into a deaerator when one is available.

Carbon dioxide is also generated in steam boilers by the decomposition of

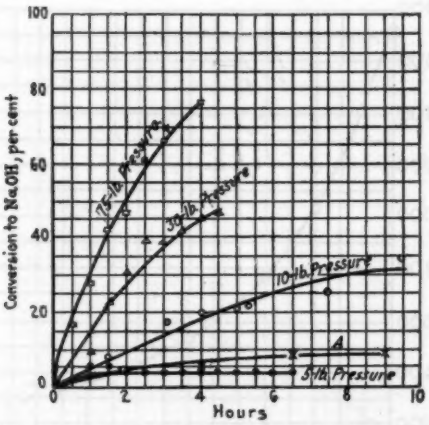

FIG. 3. RATE OF CONVERSION OF SODIUM CARBONATE TO SODIUM HYDROXIDE IN STEAM BOILERS

sodium carbonate (soda ash), which is commonly added to feed water for the removal of scale-forming matter. The influence of pressure conditions on the rate of decomposition of sodium carbonate has been determined by R. E. Hall and the author and is charted in Fig. 3. The reaction is: $Na_2CO_3 + H_2O + \text{heat} = 2NaOH + CO_2$.

Evidently the use of soda ash may be a serious source of contamination of steam in boilers operating at more than 5 pounds pressure, but below this pressure the rate of decomposition is very slow. The operating conditions governing this important reaction form a convenient basis for classification of steam systems with respect to boiler water treatment.

High Pressure Systems

Treatment of boiler water to secure pure steam from boilers carrying over 5 lb. pressure should take into account the dissociation of soda ash. This subject involves a discussion of the chemistry of boiler water treatment and is of particular concern to those operating heating plants where the scale forming

problem and the production of pure steam have to be considered together in selecting a suitable system of boiler water treatment. It is not the intention to discuss this phase of the subject in detail here but those interested will find further discussion in the references given.[2] The main point to be kept in mind in treating boiler feed water for high pressure steam plants to prevent acidity of the steam is to avoid the presence of an excess of sodium carbonate in the feed water.

Treatment of the water external to the boiler is preferable. If a zeolite softening process is used, most of the sodium bicarbonate formed should be broken up by the addition of sulphuric or phosphoric acid followed by removal of the free CO_2 in a degasifier.[3] The latter type of apparatus or a well-vented open heater operating at 210 deg. fahr. should be used wherever possible for the removal

TABLE 1. SOLUBILITY OF CALCIUM HYDROXIDE AT VARIOUS TEMPERATURES

Deg. Cent.	Deg. Fahr.	$Ca(OH)_2$, Parts per Million
0	32	1729
20	68	1623
40	104	1373
60	140	1135
80	176	884
95	203	765
120	248	409
150	302	224
190	374	111

of excess oxygen and carbon dioxide. Where the free oxygen is reduced below 0.03 cc. per liter, a certain amount of carbon dioxide acidity in the steam may be tolerated.

When the soda-lime process is used, the smallest excess of soda ash should be added. It is a difficult problem at present to reduce scale-forming sulphates to a minimum without having a certain excess of soda ash in the water, but this can be reduced by substituting sodium aluminite for part of the sodium carbonate. When the water carries only temporary hardness (due to bicarbonates of calcium or magnesium), calcium hydroxide (hydrated lime), with a small amount of a coagulant where necessary to assist in flocculation, are the only chemical reagents required. The solubility of calcium hydroxide decreases as the temperature rises, as shown in Table 1.

When there is very little permanent hardness (CaSO4) in the water and no means available for external treatment, an excess of calcium hydroxide may be carried in steam heating boilers to fix any free carbon dioxide introduced with the feed water over a considerable period. At any rate the concentration should be well within that required to give a saturated solution.

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[2] *Bulletin No. 24*, Carnegie Institute of Technology, "A Physico-Chemical Study of Scale Formation and Boiler-Water Conditioning," by R. E. Hall, G. W. Smith, H. A. Jackson, J. A. Robb, H. S. Karch and E. A. Hertzell; "Corrosion—Causes and Prevention," by F. N. Speller (McGraw-Hill Co., 1926), Chapters XI and XII.

[3] "Zeolite Water Treatment in a Large Central Heating Plant," by A. H. White, J. H. Walker, E. P. Partridge and L. F. Collins. Presented before the *American Water Works Association*, June 6–11, 1927, Chicago, Ill.

Barium hydroxide may be used to reduce scale and fix carbon dioxide in boiler water where there is no danger of the steam coming in contact with food. Barium salts are very efficient but are poisonous and relatively expensive.

The exact treatment required varies, of course, with the composition of the

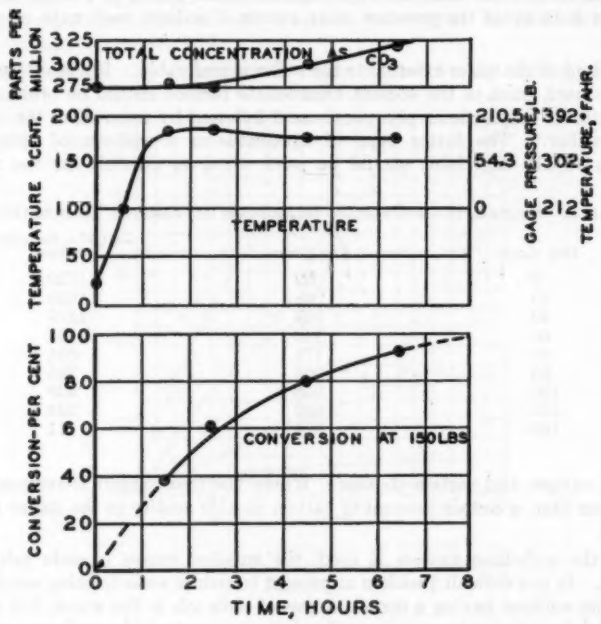

FIG. 4. RATE OF CONVERSION OF SODIUM CARBONATE TO SODIUM HYDROXIDE IN STEAM BOILERS

water supply and the results of treatment depend largely on proper control; hence it is desirable that such treatment be carried out under the direction of a competent industrial water chemist. In no case, however, should excess soda ash in any form be used in high pressure heating boilers. Many of the boiler water compounds on the market contain large amounts of sodium carbonate.

Where water treatment cannot be applied economically, a light paraffine base engine oil may be added to the steam through a sight feed lubricant attached to a vertical line arranged so that the oil will drop on to a baffle plate suspended horizontally below the oil inlet to assist in atomizing the oil. It has often been observed that steam return lines in systems using exhaust steam from reciprocating engines rarely show serious corrosion, apparently due to the protective effect of a film of heavy hydrocarbon compounds deposited on the inside of the

pipe. Oiled steam has also been used successfully to protect the interior of a steam turbine from corrosion in a case where the machine was used intermittently.

Low Pressure Systems

With proper installation and with well-regulated operating conditions, there should be little trouble due to corrosion in systems where the steam is generated at less than 5 lb. and where the condensate is returned to the boiler, except where the water carries over 2 or 3 grains per gallon of bicarbonates. Bicarbonates will be decomposed slowly at these boiler temperatures and a small amount of acidity in the steam will result, but much of the corrosion in such systems will probably be due to oxygen drawn in through leaks and in the make-up water Under these conditions caustic soda may be added to the boiler water to combine with any free or half-bound carbonic acid to form carbonate of soda, which is fairly stable at these temperatures, in the presence of an excess of caustic alkalinity.

The boiler water (according to the practice suggested in the *A.S.M.E.* Rules for the Care of Power Boilers, p. 81) should carry sulphates at least equal in amount to the alkalinity to guard against caustic embrittlement. There does not appear to be any evidence that this trouble occurs in low pressure boilers, but it is well to observe this precaution in using caustic soda, and where necessary, add for this purpose sufficient sodium sulphate to comply with this recommendation. The most convenient procedure in using this compound would probably be to add an excess of about 100 p.p.m. to the water in the boiler initially and more when the water fails to show a strong pink color when tested with a phenolphthalein indicator.[4] Flake caustic should be dissolved in hot water and added as needed. The interval between treatments depends, of course, mainly upon the amount of blow-down and this should usually be kept at the least amount necessary to discharge sludge. One full opening and closing of the blow-off valve per day is usually sufficient. Those in charge should understand that every gallon of raw water added to the boiler carries in with it more oxygen and carbonic acid. Considerable damage has resulted by unnecessary addition of raw feed water caused by excessive blowing down or leakage around the blow-off valve. In larger systems it would probably pay to meter the make-up water.

A series of tests made at the National Tube Company Research Laboratory, using a small boiler operating at from 2 to 5 pounds pressure, indicate that the CO_2 in the condensate may be kept under 3 p.p.m. (pH 6.8) by maintaining a ratio of hydroxide to carbonate alkalinity of $2^1/_2$ to 1. The CO_2 might be permitted to run somewhat above this without serious effects if the dissolved oxygen is kept relatively low. There is at present a lack of information on the effect of various proportions of CO_2 and free oxygen on the rate of corrosion in distilled water. Any boiler water treatments should, of course, be tested out under working conditions in order to determine the proper limits of treatment and means of control to obtain the best results.

The carbonate of soda may continually increase and finally reach the point perhaps where too much caustic will be needed to prevent dissociation unless the blow-down is increased or the water changed.

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[4] The pounds of caustic soda required to give an excess of 100 p.p.m. in boiler = gallons of water in boiler × [grains/gal. $Ca(HCO_3)_2$ × 0.00007 + (gr./gal. $Mg(HCO_3)_2$ × 0.000148)] × 6.

The return water may carry a considerable amount of free oxygen (2 and 3 cc. per liter). As pointed out before, this may be prevented from entering the boiler by passing the hot condensate through a filter made of steel scrap. A suitable grade of ribbon-shaped scrap steel turnings broken up for this purpose is now available for use in deactivators for hot water supplies and would probably also serve this purpose. This kind of scrap has been used for two years without caking or obstructing the flow. It is easy to build or procure a tank so designed that this material may readily be added and removed.

As calcium carbonate is slowly dissociated at high boiler temperatures it is probably impractical to secure steam entirely free from carbon dioxide when any residual carbonates are present in the boiler water.

Extra heavy pipe is commonly used for returns and all radiator nipples.

In all new systems it is recommended that a short test pipe be installed on a by-pass at some convenient and vulnerable point so that the action of the steam may be detected before serious damage or leakage occurs. It would be well to have a good industrial water chemist check the water treatment by analysis of the boiler water and steam at intervals, at least until the right amount and period treatment and blow-down is established. This should not take much time nor run into considerable expense as one man could attend to quite a large number of plants after the system of testing has been properly established.

Summary

1. Corrosion in steam heating systems is confined mainly to the returns and varies widely in different localities and sometimes in the same locality, due to variations in the water and in operating conditions.

2. There does not seem to be any necessity to use a more costly material for piping than wrought iron or steel, between which long experience indicates no material difference in durability when used for this purpose.

3. The amount of dissolved oxygen and carbon dioxide present determines the extent of corrosion. The carbon dioxide should be low, especially when any considerable amount of oxygen is present.

4. The carbon dioxide in the condensate comes mostly from the dissociation of bicarbonates or carbonates in the boiler. For this reason sodium carbonate should not be used for internal treatment of water in heating boilers.

5. In high pressure plants the water should be pretreated to remove free and half-bound CO_2 and scale-forming matter without leaving more than a slight excess of sodium carbonate. The water should be thoroughly deaerated before entering the boiler.

6. In low pressure steam boilers (less than 5 lb. pressure) where corrosion occurs in the returns, an excess of caustic soda with an equal amount of sodium sulphate should be maintained in the boiler water. The hydroxyl alkalinity should be at least twice the carbonate alkalinity. This may be controlled by testing samples of boiler water and the condensate.

7. All returns should be sealed, and every precaution taken to prevent unnecessary leakage of air into the system. Oiling the steam will afford substantial protection to steam piping.

APPENDIX

A series of tests were recently carried out in the Department of Metallurgy and Research of National Tube Co., by F. N. Speller and R. R. Kylander, using a small experimental steam boiler, to determine the acidity of the condensed steam with and without boiler water treatment. A prepared feed water was used containing calcium bicarbonate. The treatment consisted in adding excess of hydroxide alkalinity (NaOH or $Ca(OH)_2$) to retard the distillation of carbonic acid with the steam. These tests indicate the necessary hydroxide concentration for this

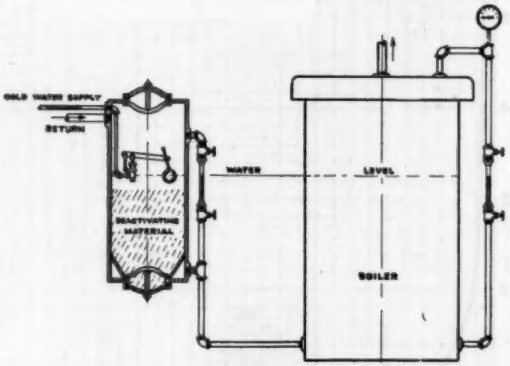


FIG. A. SET-UP OF DEACTIVATOR (OXYGEN FILTER) FOR FEED WATER

purpose to be a function of the carbonate alkalinity of the boiler water. (See Fig. *B*).

Description of Boiler and Method of Operation

The boiler is constructed of 6 in. steel steam pipe heavily flanged and bolted at both ends. The necessary fittings include a gauge glass, safety valve, mercury pressure gauge and thermometer well. The boiler has a total capacity of 8 liters and all tests were made by first filling the boiler with 6 liters of water and making up to this level at the end of each hour.

The first few tests were made at 5 lb. pressure and then repeated at 2 lb. Very little difference in the results could be noted at these pressures so 2 lb. was used in all the following tests.

A small steam trap on the $^1/_4$-in. steam outlet pipe was used to prevent any hydroxide being carried over with the steam due to foaming. Tests on the condensate in this trap showed no trace of hydroxide.

The steam was condensed in a long $^1/_8$-in. copper coil. The size and the length of this coil insured the solution of all gases in the condensate.

Samples of boiler water were removed through a valve attached below the gauge

glass. These samples of boiler water were analyzed cold for carbonate and hydroxide by titration with phenolphthalein and methyl orange as indicators.

Method for Testing Boiler Water in Steam Heating Plants for Alkalinity

This method suggested by Dr. R. E. Hall makes use of a simple testing cabinet for control work in boiler houses. A diagram of this cabinet,* together with direc-

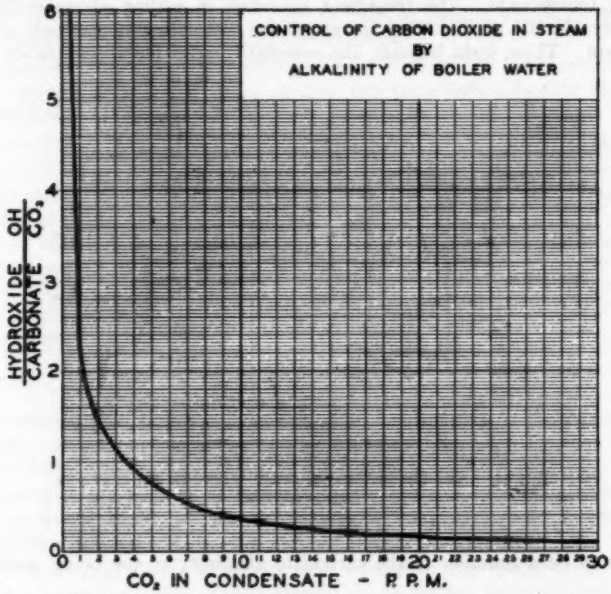


FIG. B. CONTROL OF CARBON DIOXIDE IN STEAM BY ALKALINITY OF BOILER WATER

tions for its operation, is shown in Fig. *C*. In this method phenolphthalein indicator is used to determine both (OH) and (CO_3). This is an advantage in control work for the end point with phenolphthalein is sharp, and the titration can be made by an engineer in the boiler room.

Reading *A* is obtained by titrating a 100 cc. sample with N/30 HCl using phenolphthalein. Reading *B* (hydroxide alkalinity) is obtained by treating a 100 cc. sample with 10 cc. of neutral barium chloride solution and then titrating with N/30 HCl using phenolphthalein.

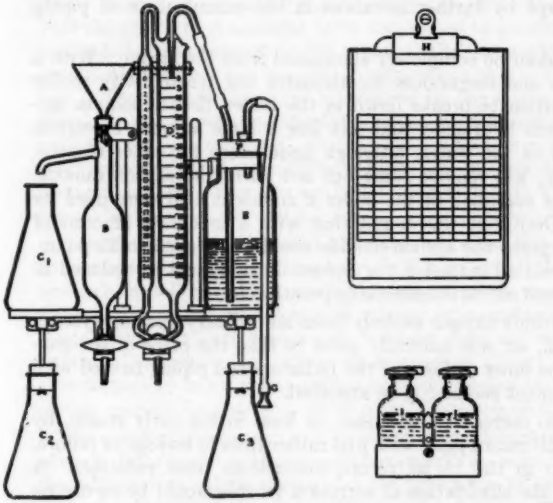
Using this method, *B* readings should not be less than $^4/_5$ of *A* readings in order to maintain a safe excess of (OH) in the boiler and a low acid content in the steam.

Method for Determining CO_2 in Steam Condensate

The condensate which has been cooled in a long copper coil under pressure, so

* Cabinet may be obtained from The Hagan Corp., Pittsburgh, Pa.

that all gases have been dissolved in it, is collected in an inverted 2-liter flask arranged as shown in Fig. *D*. Frequent shaking of the bottle will dissolve any gaseous CO_2 which may have come over in the first few minutes. It was observed during the collection of the samples that no gas was seen to bubble through the condensate after the bottle was partly filled. Tests made using a second bottle



TESTING CABINETS

Parts: *A*—Funnel. *B*—Automatic measuring pipette. *C*—Testing flasks. *D*—Burette (double or single, single preferable in heating boiler work) graduated in cubic centimeters. *E*—Bottle for Standard Acid. *F*—Rubber stoppers. *G*—Mouth piece. *H*—Report blank holder. *I*—Dropping bottles.

Supplies: 1 gallon thirtieth normal standard hydrochloric acid; 1 pint phenolphthalein; 100 filter papers; 1 quart neutral barium chloride.

FIG. *C*. CABINET FOR TESTING BOILER WATER

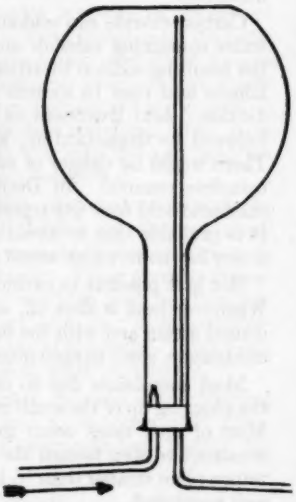


FIG. *D*. METHOD OF COLLECTING CONDENSATE

in series filled with $Ba(OH)_2$ showed that little or no CO_2 escaped solution in the first bottle under the conditions at which most of the tests were made, but on distilling bicarbonate water without treatment about 1.5 per cent of the CO_2 was collected in the $Ba(OH)_2$ when the condensate contained 70 p.p.m. CO_2. As none of the tests using treated water showed as much as 70 p.p.m. CO_2 in the condensate, the error due to this method of collecting samples may be considered negligible.

The CO_2 in the condensate was determined by adding a measured volume of N/30 $Ba(OH)_2$ to a 100 cc. sample of condensate and titrating the excess with N/30 HCl using phenolphthalein.

DISCUSSION

J. H. WALKER (WRITTEN): Mr. Speller's paper treats in a comprehensive manner the corrosion of heating systems and quite rightly states that there is no necessity for the use of more costly materials than iron or steel. This corrosion trouble is widespread but in most localities it could hardly be called serious. It can probably best be met by improvements in feedwater treatment and in heating system design and perhaps by further advances in the manufacture of piping materials.

Carbon dioxide can seldom be completely eliminated from the steam. With a water containing calcium and magnesium bicarbonates and treated with zeolite the resulting sodium bicarbonate breaks down in the boiler, first to sodium carbonate and then to sodium hydroxide, and sets free a large amount of carbon dioxide. Acid treatment of the water, although undertaken for other reasons, followed by degasification, will remove some but not all of the carbon dioxide. There would be danger of corrosion of the boiler if sufficient acid were used for complete removal. In Detroit it was found that with a moderate amount of sulphuric acid feed (35 p.p.m.) the carbon dioxide could be reduced to 25 p.p.m. It is probable that to avoid all corrosion the carbon dioxide must be reduced to a very low point which would not be commercially practicable.

Nor is it possible to exclude oxygen entirely from an ordinary heating system. Whenever heat is shut off, air will naturally enter to take the place of the condensed steam and with the inner surfaces of the radiators and piping bathed with condensate, some oxygen must necessarily be absorbed.

Most complaints due to corrosion are caused, at least in the early stages, by the plugging up of the small return pipes with rust rather than to leakage or failure. Most of such cases occur in the $^1/_2$ in. return connections from radiators. A constructive step toward the elimination of corrosion trouble would be to use no return pipes smaller than $^3/_4$ in. The additional cost would be trifling and would be well warranted.

S. T. POWELL (WRITTEN): The paper on the Corrosion of Steam Heating Systems by Dr. F. N. Speller is a very excellent discussion on this important subject. The author has presented a valuable summary of the most important factors in the mechanism of corrosion. His recommended procedure for inhibiting corrosion should be of the greatest value to those who are faced with this perplexing problem.

The writer was especially interested in Dr. Speller's comments on the use of sodium aluminate in connection with water treatment. Within recent years there has been a very rapid growth in the use of this compound both for the treatment of water in chemical softening systems and for direct treatment of water within the boilers. Sodium aluminate does not materially reduce the amount of softening chemicals employed but rather reduces the hardness resulting from better chemical reactions. By the use of this coagulant it is possible to carry higher excesses of soda without the danger of carry-over with the steam which so often happens at some plants where large excesses of soda are permitted to concentrate in the boiler waters. Probably the principal advantage in the use of this coagulant is that it reduces the hardness to a lower point than is ordinarily attained in most softening

plants. This action thereby decreases the amount of suspended matter in the boiler waters.

Sodium aluminate is now being widely used and has found considerable application in the treatment of waters used in central stations and in locomotive boilers. It is of value also in the treatment of water in heating installations since it coagulates the finely divided suspended solids. Sodium aluminate dosage for internal treatment is usually regulated by the physical appearance of the sludge. This should be in coagulated form and varied in accordance with the amount of suspended solids present in the water. The incidental reaction in the use of sodium aluminate is the removal of magnesium and to some extent sulphate hardness. The sulphate hardness is removed by the intermediate reaction of sodium aluminate on the bicarbonates for the formation of soda ash which in turn reacts with the calcium sulphate. In practically all cases sodium aluminate is used in conjunction with other auxiliary chemicals to complete softening. The most common softening reagents used in conjunction with this alkaline coagulant are caustic soda, soda ash and tri-, di- or mono-sodium phosphate.

Recent study has indicated that the use of sodium aluminate possesses the unusual property of removing silica. The presence of silica in relatively small amounts in boiler feed water is highly objectionable since when it concentrates in the boiler it may form silicates of calcium or magnesium. These deposits are excessively hard, adhere tenaciously to boiler steel and are high heat resisting materials. For this reason very small amounts of silicate scale may cause considerable damage to boiler tubes or plates due to overheating of the metal. The value of this reagent for the removal of silica, therefore, is of great importance.

The use of alkaline coagulants as auxiliary treatment to chemical water softening offers a very fruitful field of research especially in respect to the removal of silica, the inhibition of sulphate scale and the prevention of carry-over from boilers due to finely divided suspended solids.

H. R. LINN: I think Mr. Speller has given us a very timely warning here, but on the last page, in the last paragraph, he recommends oiling the steam to overcome part of this trouble. One of the biggest troubles in low-pressure heating plants is oil in the steam. It causes a lot of priming and to remove that oil in the steam there are any number of boiler compounds on the market which personally I have found hard to get out of the boiler after you put them in; that is, to get the effect of them out. I would like to ask Mr. Speller if he has had any experiments with that.

F. N. SPELLER: The suggestion to oil the steam when no other remedy seems practical was derived from experience with the use of exhaust steam from steam engines. Several buildings that we have examined showed the heating system to have been preserved until they changed from their own exhaust steam to steam purchased from central heating companies. We found what apparently was a paraffin film deposited over the entire interior surface of the return pipe system.

Of course, excess of oil must be kept out of the boiler. I only referred to the use of oil in passing as a fairly effective remedy where for any reason the quality of the steam cannot be controlled. We had an interesting experience once in the use of oil in steam in stopping the corrosion of a steam turbine during the war.

The Duquesne Light Company had a turbine which had given a great deal of trouble and they could not replace it readily at that time. It was suggested that they add a paraffin oil to the steam and the result was that this turbine ran for several years afterward without any further trouble. They had to be careful not to get too much paraffin on the blades or casing, but a little attention to regulation of the oil gave satisfactory results.

No. 796

THE TESTING OF LOW PRESSURE STEAM HEATING BOILERS

By L. S. O'BANNON,[1] LEXINGTON, KY.

NON-MEMBER

THE purpose of this report is to give the results of a few experiments conducted at the University of Kentucky, designed to furnish information bearing on several important features of the tentative Code for the Rating of Low Pressure Solid Fuel Steam Heating Boilers.

The chief topic of the paper is a comparison of Test Method *A* and Test Method *B*, alternative methods for measuring the quantity of steam delivered by the boiler. Test Method *A* measures the output of the boiler by delivering the steam to a condenser and weighing the condensate. Test Method *B* measures the water fed into the boiler and requires the boiler water level to be the same at the end of the test as at the beginning.

Description of the Boiler Testing Laboratory

The accompanying diagram of set-up for testing low pressure heating boilers, Fig. 1, shows the laboratory equipment assembled for the tests. The layout differs in no respect from the usual scheme in any of the essential requirements, but a few special features may perhaps justify the following detailed description.

The floor space occupied is 18 ft. x 67 ft. There is room for 6 boilers on the test floor at one time. An induced draft fan connected to an 18-in. tile flue in a trench extending the length of the room furnishes the necessary draft. The steam outlets of the boilers are connected to an overhead main, terminating in a condenser at one end of the room. The calibrated tanks for measuring feedwater are in the opposite end of the room. An instrument panel, or gauge board, hangs from an overhead trolley and may be moved from one end of the row of boilers to the other. Fixtures are provided for holding it rigidly in place when once moved into position for connecting the instruments to the boiler under test.

Beginning with the feed water system, the source of supply is water from the city mains. The water enters the bottom of the measuring tanks, and compresses the air in the top of the tanks. The water in one tank is fed to the boiler while the other tank is being filled. A system of double valves, with the space between

[1] Associate Professor of Heat Engineering, University of Kentucky.

Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

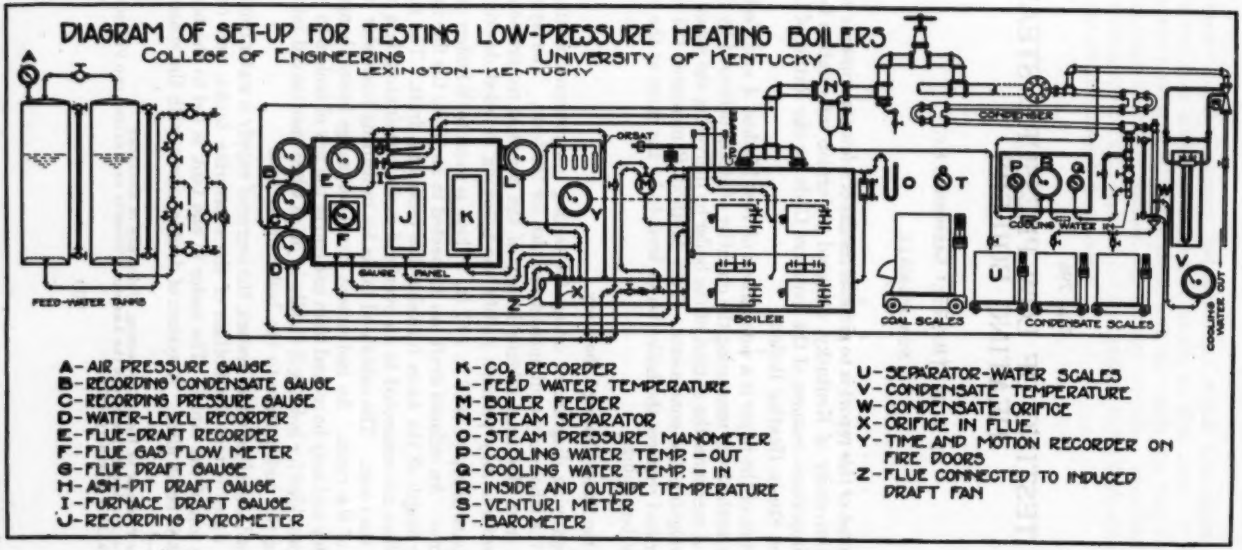


FIG. 1. LABORATORY EQUIPMENT ASSEMBLED FOR TESTING LOW PRESSURE HEATING BOILERS

two adjacent valves relieved to the atmosphere when the valves are closed, prevents any error which otherwise might occur by water by-passing the tanks through leaky valves and getting into the feed line without being measured.

The temperature of the feed water is recorded by a recording thermometer, and a well is provided in the feed water line for a mercury-in-glass thermometer. The feed line branches at the boiler; one branch leads directly to the boiler, and the other goes to the boiler through an automatic boiler feeder. The automatic boiler feeder is superior to hand feed. It continuously maintains a constant water level for a given load, and relieves the test crew of the necessity of regulating the feed valve. The principal objection to the boiler feeder is that the water level is not maintained at the same level for all rates of evaporation. This is not a practical disadvantage. It merely causes a departure from the ideal condition of a constant water level if the rate of evaporation varies much during the test.

A differential pressure gauge mounted on the instrument panel records the level of the water in the boiler. It shows the fluctuations due to boiling and to priming during the test as well as it supplies an impersonal record of the level at the start and finish of the test.

The steam pressure is read from a mercury manometer at the boiler and is recorded by a recording pressure gauge on the instrument panel.

The steam leaving the boiler passes through a steam separator and then into the steam main. The separator drain is piped to a barrel resting on scales. The level of the water in the pocket of the separator is marked on the separator gauge glass at the beginning of the test and the water is blown down periodically during the test to the original mark and weighed. The pipe, pipe fittings and separator are covered from the boiler outlet to a distance several inches beyond the separator.

There is a drip pocket at the bottom of the riser connection to the steam main. The condensate from this drip is let out through a valve into a bucket and weighed. The water collected amounts to about 1 lb. per hour.

The gate valve in the connection to the steam main is regulated by hand to control the boiler steam pressure.

The steam main is a 4-in. pipe and is not covered. The end of the main branches through six 4 in. x 4 in. x $1^1/_4$ in. tees into the six sections of the double pipe condenser.

The double pipe return bends and tees which constitute essential parts of the condenser are the familiar water cooler fittings used largely in refrigeration plants. The inside pipe through which the steam and condensate flow is $1^1/_4$-in. brass. The outside pipe is 2-in. galvanized wrought iron. The cooling water flows through the annular space between the two pipes. The condenser is constructed on the counter-flow principle. The cooling water is supplied to each section from a 2-in. header at the bottom of the condenser, and leaves through a 2-in. header at the top. The condensate is collected in a 2-in. header which is vented to the atmosphere. The water is drained from the header through a 2-in. vertical pipe, in the bottom of which is a small orifice. A water gauge shows the height of water above the orifice. The maximum range of head on the orifice is 40 in. of water. Different size orifices are provided for different rates of evaporation. The head on the orifice is recorded continuously by a recording pressure gauge mounted on the instrument panel. The rate of flow being proportional to the square root of the

head on the orifice, changes in the rate of evaporation may be noted at any instant. The condensate leaving the orifice is caught in a funnel and delivered through directing valves to either one or the other of two tanks mounted on platform scales. There is a small gauge panel near the condenser on which are mounted indicating thermometers for the cooling water in and out, and also a two-pen recording thermometer which registers the outside temperature and the room temperature. The amount of cooling water used is regulated to keep the condensate temperature down to about 100 deg. fahr. A continuous record of the condensate temperature is also obtained by means of a recording thermometer.

The double pipe type of condenser was selected in order to eliminate the necessity of running leakage tests before each official boiler test, as would be required if the ordinary type of surface condenser were used. There is not a test code in existence that does not demand a condenser leakage test to be made preceding the test of the main equipment when the weight of the condensate from the condenser is one of the important items to be determined. It is impossible to test the condenser under the same temperature conditions as prevail during its use. Exceptionally high efficiencies usually receive much publicity and at the same time are subject to a good share of suspicion. It is the opinion of the writer that a test conducted by Test Method *A*, where the bare possibility of condenser leakage is an uncertain factor, is entitled to no greater confidence than a test conducted by Test Method *B* except in one particular, and that is, condenser leakage may occur honestly without being detected, while on the other hand by Test Method *B* an apparent increase in evaporation may result from careless manipulation of the feed valve. The writer would as soon abide in the judgment of the test crew in estimating the level of the water in the boiler as to rely upon their ability to ascertain the tightness of a surface condenser. It is to be admitted that in general surface condenser leakage is of little consequence; that is to say, as a rule surface condensers are tight. No one will question average results. It is in the exceptional case that extreme precaution must prevail.

The double pipe condenser answers every argument from this point of view. There are no joints between the cooling water space and the steam space. The double pipe condenser is not offered as the ideal condenser. It occupies considerable space and is not easily moved from one location to another. It would not be difficult to modify the ordinary type of surface condenser to conform to the principle of no joints between water space and steam space.

Returning to the description of the laboratory, the coal is weighed in a box of about 1000-lb. capacity resting on platform scales. The coal is fired directly from this box into the furnace. A time-and-motion recorder keeps account of the opening and closing of the fire doors. The frequency of attention required by the fire through the fire door is automatically registered as the test proceeds.

Three inclined tube draft gauges mounted on the instrument board give the draft in the ashpit, the furnace draft and the draft in the flue. The intensity of the flue draft is also continuously traced on the chart of a recording gauge.

A recording pyrometer with a range of 0 to 1500 deg. fahr. using iron-constantan thermocouples of No. 14 B & S gauge wire is used for measuring the flue gas temperature. A combined carbon dioxide and carbon monoxide recorder is used in addition to the Orsat gas analyzer. A differential pressure recorder connected

across an orifice in the flue furnishes information concerning the rate of flow of gases. The draft is regulated by varying a resistance in the main flue leading to the fan. The usual line of laboratory apparatus is available for special tests and for calibrating instruments.

The writer is thoroughly acquainted with the general sentiment with respect to the reliability of recording instruments. All test results are calculated from the readings of the simple basic measuring instruments required by all codes. The recording gauges are valuable in making it easy to correlate the many variables which constantly influence the performance of the boiler. The continuous records assist the test crew to establish desired conditions and furnish clues leading to the explanation of unusual or disproportionate results. The chart records are valuable for supplying a picture of operating conditions to interested persons not witnessing the actual tests.

While the somewhat complete autographic features of the laboratory stand out in the foregoing description, it should be pointed out that no elaborate array of apparatus or special devices can compensate for poor management or unskillful supervision of tests.

Familiarity with basic principles, experimental technique, and a proper recognition and appraisal of values are of prime importance.

The University of Kentucky has always had facilities for testing low pressure boilers, but only recently has their interest in this phase of thermal research become intensified. On account of the limited time available for preparation and experimental work between the time a study of the boiler code was first contemplated and the time of preparing this report, only relatively simple experiments have been attempted. The following therefore is offered to the Society for discussion in anticipation of the time when the equipment described may be productive of more comprehensive results.

Comparison of Test Method *A* and Test Method *B*

Table 1 has been prepared to show the results of a test to compare the calibrated tank method and the condenser method. It is assumed that the measurement of water by means of tanks calibrated at a known water temperature is equivalent to the measurement of water at the same temperature by direct weighing. The scales on the tank water gauges were graduated after several calibrations at different times by two independent observers. Two different weighing scales previously checked by standard weights were used. The tanks are ordinary 14 in. x 60 in. domestic water boilers. Each tank when operated to the capacity of the graduated scales will furnish 230 lb. of water with each emptying. The distance between 1-lb. graduations on the tank scales is approximately 0.18 in. The length of a 1-lb. division on the beams of the platform scales used for weighing condensate is approximately 0.07 in. It is possible to estimate fractions of a pound in reading the graduated scales on the measuring tanks to a greater degree of accuracy than it is possible to obtain by estimating fractions of a pound on the condensate scales.

The steam heating boiler used in the test has a water capacity of 1150 lb. up to the normal water line. One inch difference in level near the normal water line amounts to 90 lb. These weights are for water at 220 deg. fahr.

The duration of the test was 10 hr., starting at 10:10 A.M. after the boiler

had been steaming for nearly an hour. Fig. 2 is a graphic log of the operating conditions during the test. Table 1 gives the accumulated total weight of condensate and feed water, that is, the output by Test Methods *A* and *B*, respectively, for each ten-minute interval of the test. The difference in weight by the two methods is shown, and also the height of the water level in inches above or below the water level at the start of the test. The water levels were read from a scale attached to the gauge glass on the water column.

It is interesting to note the uniform correlation of high and low water level with high and low tank weight.

The graphic log shows that from the beginning of the test until 6:00 P.M. the average rate of evaporation was fairly uniform. If in the table the apparent error or difference between tank weight and condenser weight at the times when the water level was observed to be the same as at the beginning of the test is noted, it is found that at 2:50 P.M. the tank weight was 26.5 lb. high; at 3:40, 7 lb. low; at 3:50, 6 lb. low; at 4:30, 2.5 lb. high; at 4:50, 6.5 lb. low. If it is assumed that the condenser weight is correct, and that the test might have terminated at any one of those times when the water level was the same as at the beginning of the test, the percentages of error for Test Method *B* for the above values are, respectively, 0.63, 0.14, 0.12, 0.04 and 0.01 per cent. These errors are well within the limit required. With Test Method *B* it would have been improper to have stopped the test at the end of any other period than those considered.

At six o'clock the test crew had instructions to gradually decrease the load on the boiler until the flue gas temperature had dropped to 500 deg. fahr. It might be well to add here that the draft was kept practically constant during the major part of the test, and the fireman had instructions to maintain a flue gas temperature around 950 deg. fahr. by firing as often as necessary and by giving the fire whatever attention was required.

Referring to Table 1 and to Fig. 2, it will be noticed that toward the end of the test as the evaporation was falling off the boiler level was high and the tank weight was low. The condenser was getting more steam than could be accounted for by the tank weight and water level in the boiler. This was explained by assuming that at the beginning af the test the average water level was considerably higher than that indicated by the gauge glass, on account of water being banked up in the rear of the boiler in the direction of flow toward the steam outlets due to the higher rate of evaporation. At the end of the test when the evaporation was relatively low this water settled down and increased the apparent water level as indicated by the gauge glass. If 25 lb. of water additional had been supplied to the water in the boiler near the end of the test, the tank weight and condenser weight would have been the same, but the water level would have been about 1.3 in. higher that at the beginning of the test. Considering the low rate of evaporation at the end of the test we may assume that the surface of the water in the boiler at this time was nearly level. If a uniform upward slope of the water surface from front to rear at the beginning of the test is assumed, the level of the water in the rear of the boiler would have to be 2.6 in. higher than the level at the front of the boiler in order to account for a mean level of 1.3 in. That this is quite possible was demonstrated later by putting two extra water gauges on the boiler; one near the middle of one side, and one at the rear of the boiler. The regular gauge was

TABLE 1. TOTAL WEIGHT OF WATER

Time	Calibrated Tanks	By Condenser	Amount Tank Weight Is High	Amount Tank Weight Is Low	Boiler Water Inches High	Level Inches Low
10:10 A.M.	0	0		0		
20	155	155.5		0.5	0.0	0.0
30	301	304.0		3.0		0.25
40	497	440.5	56.5		0.10	
50	662	613.0	49.0		0.10	
11:00 A.M.	779	772.5	6.5		0.75	
10	933.5	927.0	6.5		0.10	
20	1068.5	1066.5	2.0		0.60	
30	1228.5	1221.0	7.5		0.50	
40	1394.5	1347.5	47.0		0.60	
50	1516.0	1508.0	8.0		0.60	
12:00 P.M.	1669.5	1659.5	10.0		0.30	
10	1816.0	1810.0	6.0		0.30	
20	1955.5	1949.5	6.0		0.40	
30	2089.0	2089.0	0.0		0.70	
40	2224.5	2214.5	10.0		0.20	
50	2355.5	2364.0		8.5	0.50	
1:00 P.M.	2446.5	2525.5		79.0		0.70
10	2544.5	2680.5		136.0		1.90
20	2682.0	2821.0		139.0		1.50
30	2874.5	2975.5		101.0		1.00
40	3059.5	3122.0		62.5		0.50
50	3221.0	3276.5		55.5		0.75
2:00 P.M.	3436.0	3438.0		2.0	0.70	
10	3603.5	3591.5	12.0		1.00	
20	3744.5	3738.0	6.5		0.40	
30	3900.5	3906.5		6.0		0.40
40	3909.0	4083.5		174.5		1.60
50	4253.5	4227.0	26.5		0.00	0.00
3:00 P.M.	4371.5	4383.5		12.0	0.60	
10	4547.0	4541.0	6.0		0.30	
20	4705.0	4714.5		9.5		0.20
30	4872.0	4866.0	6.0		0.25	
40	5019.5	5026.5		7.0	0.00	0.00
50	5180.0	5186.0		6.0	0.00	0.00
4:00 P.M.	5325.5	5329.5		4.0	0.50	
10	5464.0	5456.0	8.0		0.40	
20	5614.0	5615.5		1.0	0.40	
30	5763.5	5761.0	2.5		0.00	0.00
40	5925.5	5940.5		15.0		0.20
50	6094.5	6101.0		6.5	0.00	0.00
5:00 P.M.	6256.0	6248.5	7.5		1.00	
10	6413.0	6397.0	16.0		0.70	
20	6549.5	6555.5		6.0	0.30	
30	6662.0	6735.0		73.0		0.70
40	6813.5	6877.5		64.0		0.70
50	7004.5	7064.0		59.5		1.00
6:00 P.M.	7223.0	7220.5	2.5			0.10
10	7397.5	7366.0	31.5		0.00	0.00
20	7541.0	7499.0	42.0		0.75	
30	7664.5	7613.0	51.5		1.25	
40	7740.0	7736.0	4.0		0.60	
50	7794.5	7861.5		67.0		0.50

Time	Calibrated Tanks	By Condenser	Amount Tank Weight Is High	Amount Tank Weight Is Low	Boiler Water Level Inches High	Boiler Water Level Inches Low
7:00 P.M.	7908.5	7972.0		63.5		0.10
10	8042.0	8056.5		14.5	0.00	0.00
20	8151.0	8167.0		16.0	0.40	
30	8250.5	8264.5		14.0	0.60	
40	8352.5	8372.0		19.5	0.80	
50	8430.5	8446.5		16.0	1.00	
8:00 P.M.	8506.5	8519.0		12.5	1.00	
10	8582.0	8598.5		16.5	1.00	
20	8649.0	8664.0		15.0	1.00	
30	8707.0	8722.0		15.0	1.00	
40	8750.0	8775.0		25.0	1.00	

at the front of the boiler. When the boiler was forced to the priming point the middle gauge showed a level 1.5 in. higher than the front gauge, and the rear gauge showed a fluctuating level from 4 to 6 in. higher than the front gauge. Proportionately smaller differences in level were observed at lower rates of evaporation.

If we attempt to correct the tank weights in Table 1 for the observed difference in water level at the end of any period and compare this weight with the condenser weight the results will not be satisfactory for the reason that the gauge glass readings do not give the true height of the water level in the boiler. This correction can rightly be applied only when the rate of evaporation is the same as at the beginning of the test. The amount of water accumulating in the rear end of the boiler will vary also with the height of water in the boiler, and of course, from this standpoint the correction is never valid since it can be applied only when conditions are the same as at the beginning of the test, in which case no correction is needed.

The question naturally arises as to how near the tank weight and condenser weight would check if both methods were used to weigh the same volume of water.

TABLE 2. TOTAL WEIGHT OF WATER

Time	Calibrated Tanks	By Condenser	Amount Tank Weight Is High	Amount Tank Weight Is Low
2:20	0	0	0	0
2:30	220.5	132.5	88.0	
2:40	396.5	329.0	67.5	
2:50	590.0	523.0	67.0	
3:00	786.0	719.5	66.5	
3:10	978.5	912.0	66.5	
3:20	1166.5	1100.5	66.0	
3:30	1364.0	1299.5	64.5	
3:40	1551.5	1486.5	65.0	
3:50	1739.0	1674.0	65.0	
4:00	1739.0	1742.5		3.5

To try this, water was allowed to flood the whole system and overflow through the condenser. The supply valve was then closed and the condenser was allowed to drain until the flow of water ceased. The supply valve was then opened and the water was measured by both methods for 1 hr. and 40 minutes. At the end of the test the condenser was allowed to drain in the same manner as at the beginning

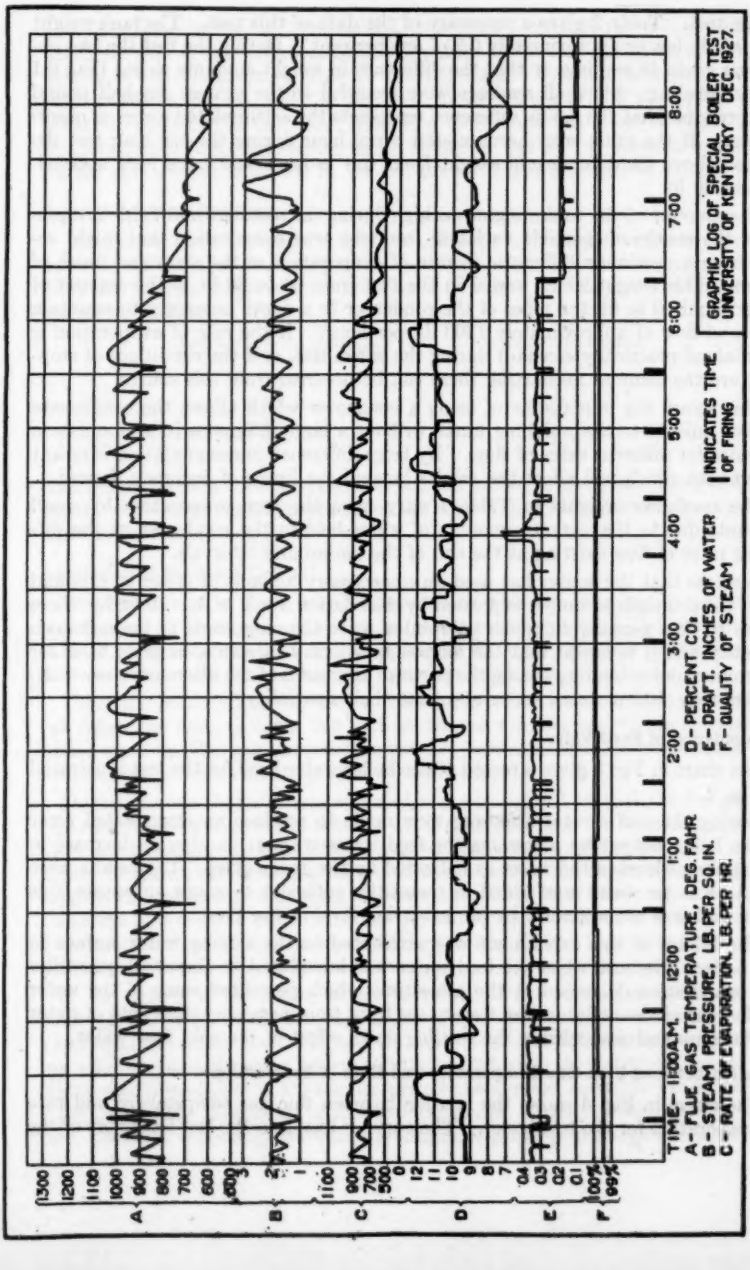

TIME— 11:00 A.M. 12:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00
A - FLUE GAS TEMPERATURE, DEG. FAHR
B - STEAM PRESSURE, LB. PER SQ. IN.
C - RATE OF EVAPORATION, LB. PER HR.
D - PERCENT CO2
E - DRAFT, INCHES OF WATER
F - QUALITY OF STEAM
INDICATES TIME OF FIRING
GRAPHIC LOG OF SPECIAL BOILER TEST
UNIVERSITY OF KENTUCKY DEC. 1927.

FIG. 2. GRAPHIC LOG OF SPECIAL BOILER TEST

of the test. Table 2 gives a summary of the data of this test. The tank weight was 3.5 lb. low or approximately 0.2 of one per cent. During the test the two observers made 40 readings so that the difference in weight amounts to less than 0.1 lb. per reading. Since all readings were recorded to the nearest one-half pound it is probable that the 3.5 lb. difference represents the accumulated errors of observation. If the same error accumulated every hour during the ten-hour test described above the difference in weight from this cause would have been approximately 26 lb.

The amount of the tank weight was high during the test shown in Table 2, represents the maximum possible variation from the true evaporation that might result from a maximum difference in rate of evaporation at the start and finish of a test. This weight which varied in the test from 64 to 88 lb. is the amount of water required to fill the pipes of the condenser to a depth necessary to maintain a rate of flow of approximately 1300 lb. per hour. If the rate of evaporation is maintained practically constant during the entire test, or if the conditions of stopping are the same as at starting there can be no error from this source.

This shows the importance of using a condenser which allows the condensate to flow quickly to the weighing tanks without a large difference in accumulation of water for different rates of flow. By large difference in accumulation is meant an amount which will affect the results beyond the limits of accuracy desired.

The condenser weights in Table 1 vary from the true evaporation by small amounts due to the various amounts of water held in the condenser at the different rates of flow existing at the end of the ten-minute intervals.

It seems that the writer has used an unnecessary amount of space to expound upon the principle so simply expressed by the relation $B-X=A$. However, there seems to be a genuine difference of opinion as to the magnitude of the unknown quantity and it is hoped that the data supplied may furnish a tangible basis for a common understanding among the partisan advocates of the alternative methods. Others may find material to substantiate their neutrality.

Manipulation of Feed Valve

The chart in Fig. 3 gives a record of the boiler water level for the test illustrated in Fig. 2.

During the test several attempts were made to produce an exaggerated error in the boiler output by increasing the feed water without causing an increase in the apparent level of the water as indicated by the gauge glass. The results were negative as no water was added in quantities sufficient to cause an appreciable error that was not apparent by an increasing level in the glass.

The failure of this experiment was attributed to the sloping water surface in the boiler. Because when the feed water was introduced in abnormal quantities the evaporation decreased at the same time which permitted some of the water in the rear of the boiler to flow toward the front thus increasing the height of water in the glass and neutralizing the settling down effect of the cold feed water.

Relation between Flue Gas Temperature and Rate of Evaporation

The curve in Fig. 4 shows the relation between flue gas temperature and rate of evaporation for the test boiler. The curve is based on the last few hours of the

test illustrated in Fig. 2. The straight line drawn through the points makes the algebraic sum of the distances from the points to the line a minimum. The line intersects the temperature scale at 294 deg. fahr. The line intersects 700 deg. fahr. at 586 lb. per hr., and 730 deg. fahr. at 630 lb. per hr. If the 630 lb. per hr. were corrected to 700 deg. fahr. according to the formula given in the code, the evaporation at this temperature would be 596 lb. per hr. Compared to the point on the curve which is at 586 lb. per hr. the difference amounts to 1.7 per cent.

Interval between Readings

In an attempt to show how widely the computed average of flue gas temperatures taken at different intervals may vary, the temperature was read every five minutes from the flue gas temperature chart, Curve *A*, Fig. 2, and the average temperature computed as follows:

Interval between Readings, Minutes	Average Temperature, Deg. Fahr.
5	869.2
10	865.9
15	872.6
20	872.8

The differences are small in this case but the writer believes that mere chance of greater differences occurring precludes the recording of test data at intervals longer than 10 minutes.

Limitation of Moisture Content

The boiler used in these tests delivers steam with less than $^1/_2$ of one per cent moisture at all rates of evaporation up to the priming point. The percentage of moisture was obtained from the gross weight of water collected in the separator with no corrections for radiation or separator efficiency.

Using the automatic boiler feeder, which allows the water level in the boiler to fall below the normal water line with increasing evaporation, the boiler starts to prime when the flue gas temperature reaches 1200 deg. fahr., corresponding to an evaporation of approximately 1300 lb. per hour.

During one test the boiler was operated over a period of 1 hr. with the flue gas temperature reaching high peaks between 1200 deg. fahr. and 1290 deg. fahr. immediately after stoking the fire, which occurred about once every 10 minutes. As the higher temperatures were reached water would rise in the separator pocket very rapidly. Sometimes at a uniform rate over a period of 20 or 30 seconds with a total collection of 3 or 4 lb., but more often the water would come over in intermittent, disconnected slugs, filling the separator completely in 1 or 2 seconds with quantities of water equal to a gallon or more.

If the quality of the steam were determined at the instant when the priming occurred the figure would be much closer to zero than to 100 per cent. It is obvious that the boiler could not operate continuously in this manner. The priming would necessarily occur intermittently so that when the weight of the separator water was spread over a ten-minute period the average moisture never exceeded 7 per cent. The percentage of moisture calculated for an extended period, therefore, does not necessarily indicate the degree of priming although the percentage

so calculated may be an objectionable quantity, and may in itself indicate that for a given boiler priming has occurred.

The 2 per cent moisture limitation specified in the code is desirable since it specifies a reasonable limit to the moisture content of wet steam. Also it may be a fact of general experience that boilers must prime in order to deliver steam with a moisture content exceeding 2 per cent. Again, if priming means the delivery of wet

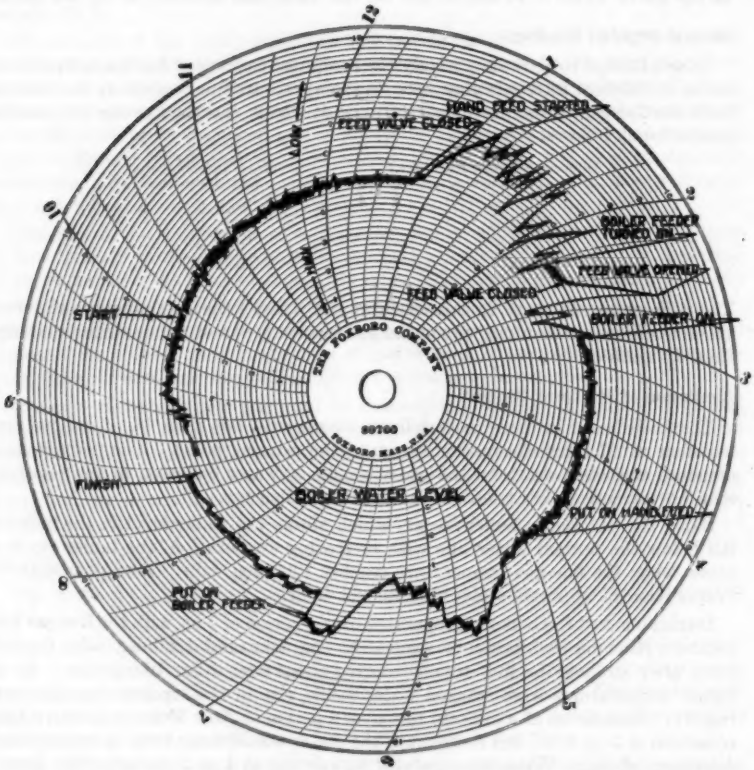


FIG. 3. CHART FROM RECORDING BOILER WATER LEVEL GAUGE

steam with a certain quality, then priming may be defined in terms of an arbitrary percentage value.

On the other hand, if priming is the carrying over of entrained moisture in a more or less violent manner, in intermittent, disconnected slugs and chugs, then let priming be defined in such homely language, and be recorded simply as a matter of fact as indicated by rapid accumulation of water in the separator. Such a con-

ception of priming has its parallel in the power plant field, where the observation and evaluation of priming is concretely exemplified by gathering up the pieces of a broken cylinder head.

It is the opinion of the writer that the 2 per cent moisture specification should stand as a limitation to the quality of wet steam; and since it should be required that the boiler be operated below the priming point during any test, it is sufficient

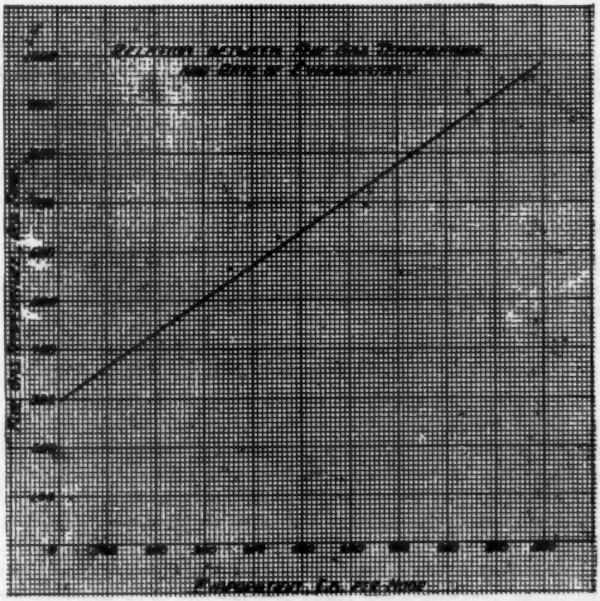


FIG. 4. RELATION BETWEEN FLUE GAS TEMPERATURE AND RATE OF EVAPORATION

to know when priming occurs without adding confusion or misconception by attempting to define priming in mathematical terms.

Duration of Test

The writer approves the recommendation of the Code Committee that the length of output tests without the determination of efficiency be such as may be included in an eight-hour working day. By allowing 3 hr. for starting, 1 hr. for stopping and running through the noon hour, the laboratory has had no difficulty in making five-hour tests during an eight-hour day.

In efficiency tests the greatest source of error is in estimating the thickness of the fuel bed at the beginning and end of the test. The following table shows the allowable error in estimating the thickness of the fuel bed for the test boiler under

consideration in order to insure a minimum error of 2 per cent in the test results with the boiler operating approximately at catalogue rating.

Duration of Test Hours	Allowable Error in Inches Thickness of Fuel Bed
8	0.41
12	0.59
16	0.79
20	0.97
24	1.19

The figures are based on the volume of fresh fuel and no allowances have been made for coking or distillation of volatile matter.

In comparing the accuracy of measurement of coal with the accuracy of measurement of feed water it should be remembered that an error of 15 lb. of coal (one shovelful) is equivalent to an error of 100 to 150 lb. of water depending upon the efficiency of the boiler.

Acknowledgment

The writer wishes to acknowledge the assistance of the following men, Research Assistants in the engineering laboratories: R. C. Porter, I. G. Watkins, Robert Spicer and Sam Shawhan.

DISCUSSION

F. C. HOUGHTEN: At the Semi-Annual Meeting of the Society in 1927 the Research Laboratory announced the policy of carrying on research cooperatively with different universities, and at that meeting an agreement was entered into with the University of Kentucky. In December, Mr. Lewis, chairman of the Research Committee, and the writer, went to Kentucky and saw what they were doing and now we have this paper. They are setting a pace at the University of Kentucky that will be hard for us to keep up with.

This paper is very timely for during the past year the question of boiler output and boiler rating has been one of paramount interest to Society members and the heating industry generally. The Society has a Committee on Boiler Rating, of which I am a member. Speaking for the Laboratory and influenced by my individual connection with the Committee on Rating Boilers, I find a good deal in this paper which should be helpful to the Committee in straightening out some of the doubtful questions it has had to contend with. In former codes for testing boilers we have weighed the feed water put into the boiler in order to determine the rate of evaporation. A new idea brought into the field and mentioned by Dr. Brabbée in his paper at an earlier meeting of the Society is that of using a condenser. The Committee on Rating Boilers is trying to develop a shorter test code and in so doing has found that a shorter test could be specified if the condenser method of determining the rate of evaporation was used. The work at the University of Kentucky in cooperation with the Research Laboratory of the A.S.H.& V.E. as indicated in this paper gives data on this subject. It gives a comparison between determining rate of evaporation by the condenser method and by weighing the feed water.

The paper gives information on the length of test necessary for determining maximum output at constant rate of steaming. This is another question on which there is no agreement. If the maximum rate of output, under some condition, is the only fact that we want to establish by a boiler test then apparently it is not necessary to run an extremely long test. The Committee on Rating had that in mind in establishing the shorter test in the code that was presented for your consideration last summer. Prof. O'Bannon's work bears out the fact that satisfactory information on maximum boiler output can be obtained in a very short period of time.

The relation between output and flue gas temperature is another question that has frequently been considered and this paper gives some information on the relation between these two factors.

The relation between moisture content of the steam, rate of steaming and the priming point is a question on which apparently few people agree. In fact, you cannot get many people to agree on what priming is. There are apparently two ideas on how priming takes place. One idea is that as the rate of output of a boiler increases the moisture content of the steam gradually increases until finally a slug of water goes over. Another belief is that the moisture content of the steam remains very low until all of a sudden a slug of water comes over. This paper gives some very interesting data on what is taking place in a boiler just before and during priming.

Again, the relation between level of water in the boiler and the priming point is a doubtful question on which this paper gives much needed information.

R. V. FROST: I was very much interested in some of the things that Prof. O'Bannon brought out. For instance, he shows that a differential pressure gauge is mounted on the instrument panel board to record the level of the water in the boiler. You will note where his connections were, just slightly above and below the normal water line of the boiler, but he did not state just how the gauge acted; whether he got satisfactory results from it. I would like to know just how accurately it did perform. It is very interesting if it works well, because every one is familiar with the performance of the water line of a boiler, how in some boilers the emulsion will take place very low down, while in others it is practically on the water line, and the result is that the water line lifts with the increase in steaming very much more in some boilers than it does in others. Therefore, it is difficult to maintain a normal water line under all conditions.

Then there are some points that he brought out on the graphic log of boiler tests. You notice that his stack temperature averages around 900 deg. His high temperature is very close to 1100 deg. and his minimum temperature is only 700 deg. His CO_2 content averages 10 per cent, the maximum 12 per cent and his low point is somewhat under 9. Those who have followed the proposed code of the Society recall the limiting conditions of 700 deg. stack temperature and a minimum of 12 per cent CO_2. Prof. O'Bannon does not give the efficiency of the boiler under this test, but it is hardly to be expected that under the result of this test the efficiency was very low. One thing that would affect the relationship between stack temperature and efficiency would be the character of the boiler, the type of boiler. Some boilers will run at a very high efficiency, over 70 per

cent, with a stack temperature of 800 deg. and above, while others cannot reach a temperature of 700 deg. under any normal draft condition.

Then in regard to the CO_2 content, from my own experience I have seen very few heating boilers that can reach 12 per cent under normal operating conditions. The average seems to be just about as Mr. O'Bannon found, around 10 per cent. Very frequently very good results will be obtained with as low as 7 per cent. That is with a deep fuel bed, too, which would naturally bring out high CO_2 content. Under those conditions we get a very low CO. Very seldom in a heating boiler does the CO content run above one per cent unless it is operated under poor draft conditions.

ANDREW VOGEL: In observing the firing period and also the capacity of the boiler, I would say that the firing for this size of boiler was altogether too frequent. A boiler having a capacity of only 700 to 900 lb. of steam per hour should not be fired so frequently. A heating plant of that small size would not justify the constant attention shown by the firing period. I would like to ask the author at what capacity he would rate this particular boiler, based on say a 6- or 8-hour firing period.

PRESIDENT ANDERSON: In order to make clear the purpose of this paper let me tell you that Prof. O'Bannon is a very modest gentleman and he hasn't told all of the story to you. There was an attempt made to set up a boiler testing plant, a plant for the testing of low-pressure boilers that would be so elastic as to take into consideration every possible variable that could be conceived in the testing of low-pressure boilers. There is no attempt here to present conclusive evidence or to analyze now any particular boiler because this laboratory has just been completed after a construction period of six months but I suggested to Mr. O'Bannon that he might show some preliminary results so as to give an idea as to what could be accomplished in a test plant of this kind.

In the first place this is a laboratory that was constructed entirely for this purpose. It was not put in the corner of a previously existing room. It is a laboratory that was designed especially for low pressure domestic boiler testing with every service facility of which we could think.

For instance, the condenser is especially designed. It seemed to us that there was no condenser that could be purchased that would quite meet the needs. A condenser must be tight, of course, and this condenser is designed with all outside packed joints so any leak would be detected. It is so designed that any laboratory can produce one. This laboratory in all details can be copied. If any one would like to duplicate this laboratory, we would be pleased to furnish drawings of the condenser and specifications for all other apparatus.

One of the interesting details about the laboratory, is a track from end to end carrying a board large enough to accommodate all the recording instruments. There was one prime objective in creating this laboratory, namely, to produce an autographic record of what goes on in a low pressure domestic boiler during operation: a complete story autographically. That does not mean that observations are not taken in the usual way. Observations are taken every 10 minutes and the autographic story is to provide a complete check on the readings of test assistants. The question of time is an important thing. The time is always

standard time, Washington time, and the readings are taken at a certain time every 10 minutes by a very carefully arranged automatic device, not depending upon human notification of time of readings. That may seem to be of no great value at first glance, but we think it is because we can secure from the Weather Bureau data in reference to outside weather conditions at any particular time. In carrying on investigations of this kind, of course, the outside temperature frequently has something to do with the problem. So does barometric conditions and all those weather variables that we are accustomed to meet in boiler testing.

So we have here a boiler testing laboratory that gives an opportunity to carry on investigations of any character. We do not expect to rush into print with a lot of facts in reference to particular boilers that are under investigation. In fact, all work done there is primarily now for the scientist and not for commercial purposes.

An automatic recording flue gas apparatus is pretty reliable, but we do not depend upon that. That must be checked up with an Orsat. An Orsat apparatus is used to give us what happens, but we found with a new apparatus and a very good one that we are getting a very nice check, but an automatic apparatus is very likely to get out of order and that is one of the dangers of using them without a check analysis, although perhaps the makers of our particular installation of CO and CO_2 apparatus will not agree with this statement.

This laboratory, then, does not propose at the present time to give any facts here that are to be used in deciding anything.

No two or three men working on a problem can cover the whole situation relative to a boiler rating problem. Those gentlemen who have been working on boiler testing may be able to suggest other apparatus that will give us valuable information, but as far as we know now, with the exception of giving us a picture of the smoke, this laboratory will give us all facts in reference to every variable entering into the testing of the low-pressure boilers.

C. E. BRONSON: I would like to ask the author a question with regard to the type of CO_2 recording apparatus used. Misleading results may be obtained when a CO_2 recording meter operating on the electrical conductivity principle is used and especially where the boiler under test is being fired with bituminous coal. Combustible gases have a different value of conductivity than CO_2 and if present in the escaping gases give a lower reading on the instrument than is obtained by an Orsat apparatus.

PROF. L. S. O'BANNON: The boiler water level gauge is simply a type of differential pressure gauge ordinarily used in connection with venturi tubes and orifices. It records the level of the water in the boiler exactly when the boiler is not steaming. That is, if you read the water column and read the gauge the readings will correspond when the water level is steady, but when the boiler is steaming there is a fluctuation in the water level and the fluctuations as observed on the glass will be, say, one inch above and one inch below, while the corresponding fluctuations on the chart will be two-tenths of an inch above and two-tenths of an inch below. However, the average weight or head of water in the boiler is recorded on the boiler level chart. The mean line of the chart record is equivalent to an observer's estimate of the mean level of a fluctuating water column.

It would be practically impossible, of course, to have a recording meter which would record the sudden and instantaneous fluctuations of the water as may be observed on the gauge glass. I was sceptical of the instrument myself at first but after we have used it for a while I am very much impressed with it and I think it would be worth while for any one doing similar work to have one of these boiler water level meters in his laboratory.

The relation between flue gas temperature and CO_2 was brought up. These tests were run with soft coal and the continuous method of firing was used. We have never attempted to rate steam heating boilers on a 6-hour or an 8-hour or a 12-hour firing period, using soft coal. If we attempted to rate this boiler say on a 4- or 6-hour firing period with soft coal, the rating would be low compared with the ordinary method of rating boilers using soft coal and firing continuously. Of course, this particular test is not a rating test. Variations in flue gas temperature, evaporation, CO_2 and other factors show up which would not show up in an ordinary test. We can watch the flue gas temperature recorder and obtain by proper manipulation almost a perfect sawtooth curve giving a rise in temperature immediately after firing, reaching a peak and gradually falling off as the coal burns out and after the next firing the temperature will rise again, then gradually fall off, and so on. The fireman can watch the flue-gas temperature chart and maintain the curve almost perfectly. If you tell him you want an average flue-gas temperature of 700 deg. at the end of a 24-hour test, he will have not less than 695 and not more than 705.

The CO_2 meter uses caustic potash as a solution for absorbing the carbon dioxide. In selecting this particular CO_2 recorder we were guided by that principle as much as anything else. We have never used an electrical type of CO_2 recorder and know nothing about this type from personal experience. We understand that all types of CO_2 recorders are usually checked against an analyzer, absorbing carbon dioxide by means of potassium hydroxide, and so we selected in the first place a recording instrument which uses the potassium hydroxide principle of absorption.

No. 797

RELATION BETWEEN OUTPUT AND OPERATING CHARACTERISTICS OF LOW-PRESSURE STEAM-HEATING BOILERS[1]

By P. Nicholls,[2] Pittsburgh, Pa.

MEMBER

Introduction

THE purpose of this paper is to discuss the relations which exist between some of the operating characteristics of low-pressure steam-heating boilers, and to give the results of some tests thereon. This investigation was undertaken to assist the Committee of the American Society of Heating and Ventilating Engineers which is drawing up a rating, or performance code for these boilers.

The fact is well known that it is difficult to duplicate exactly the results obtained in a test, and the results of tests made by different crews may vary considerably. Such lack of agreement is due to differences in the adjustment of the dampers, the method of firing, and the manipulation of the fuel bed, and sometimes to the fuel used not being exactly alike in kind or size. It follows that better agreement will be obtained as the control and manipulation are exactly duplicated.

It is essential, in formulating a code such as that contemplated, to insure that the numerical values of the operating characteristics of all boilers should be comparable. The codes and testing specifications must, therefore, include such limitations, instructions and advice that all tests will be carried through in the same manner. Detailed instructions on damper adjustment—that is, on their correct settings—are not possible, and what is required is that there shall be similarity in the combustion as measured by flue-gas analysis, and in the air admittance as indicated by the draft values.

Although the results of duplicate tests may vary and although the test points on a complete performance chart may not give smooth or logical curves, the operation of a boiler is not a matter of chance but depends upon certain fundamental laws of combustion and heat transfer. It would therefore be expected that there should be fairly definite relations between output, flue-gas temperature and composition, drafts and fuel used. Some indication of these relations was available, but your

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committee recognized that it was incomplete and that it did not have the data to justify fully the inclusion of some of the limitations proposed.

The Bureau offered to make such tests as the time available permitted, and in particular to study the relation of output to smoke-hood temperature, flue-gas analysis and smoke-hood draft.

Test Set-Up and Methods

Two cast-iron boilers that were available in the laboratory were used for the

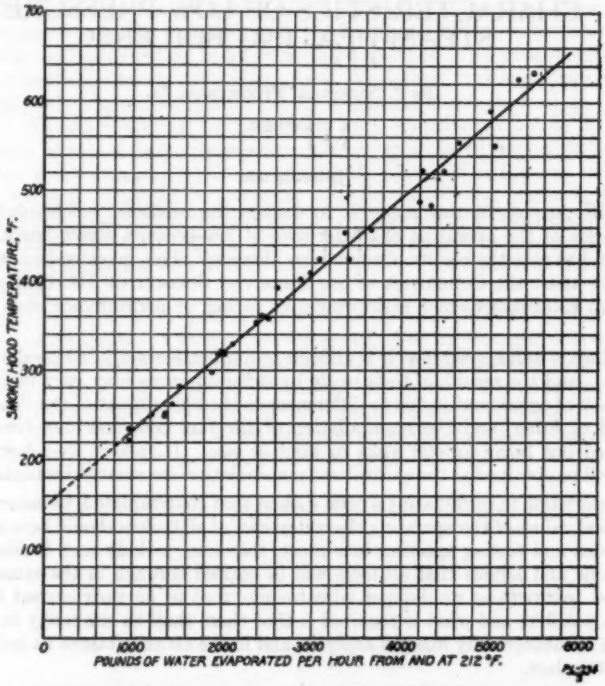

FIG. 1. RELATION BETWEEN SMOKE-HOOD TEMPERATURE AND STEAM OUTPUT WITH ABOUT 12 PER CENT CO_2 IN A STEAM-HEATING SECTIONAL BOILER HAVING 32.5 SQ. FT. GRATE AREA. INDIVIDUAL OBSERVATIONS WERE MADE FOR ONE MINUTE ON STEAM FLOW BY ORIFICE METER. FAIRMONT COKE USED

experimental work. One was a horizontal sectional boiler of 32.5 sq. ft. grate area and the other a round sectional boiler of 3.14 sq. ft. grate area. The test set-up followed the instructions of the A.S.H.&V.E. 1927 Tentative Rating Code. Fan-induced draft was available for both boilers, and the natural draft was not suffi-

cient for some of the combustion conditions required; moreover, in this investigation, ample draft permitted better control. It was unfortunate that a steel type of boiler was not available.

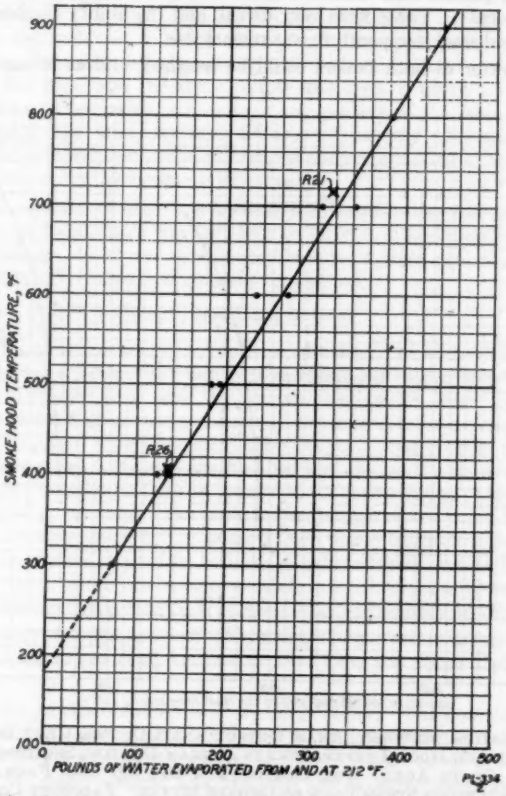

FIG. 2. RELATION BETWEEN SMOKE-HOOD TEMPERATURE AND WATER EVAPORATED WITH A ROUND CAST-IRON STEAM-HEATING BOILER, HAVING 3.14 SQ. FT. GRATE AREA. INDIVIDUAL POINTS, EXCEPT 4-HOUR TESTS R21 AND R26, ARE FOR STEAM CONDENSED DURING 10-MINUTE PERIODS. LOWELL COKE $1^1/_2$- TO 2-IN. SIZE WITH 12-IN. FUEL BED DEPTH MAINTAINED

Two methods of test were possible: (1) A number of complete tests could be made and the average values of each obtained, or (2) measurements could be made more carefully and exactly to get instantaneous values or for short periods of 5 to 15

min. during which time burning conditions were maintained constant. The investigational nature of the work made the latter method preferable, although averages of complete tests were also obtained.

In order to permit more delicate control the stack dampers were fitted with screw adjustments. These were very useful, and the ability to obtain and maintain any desired stack temperature was remarkable.

The feed water to both boilers could be weighed, and as it was necessary to

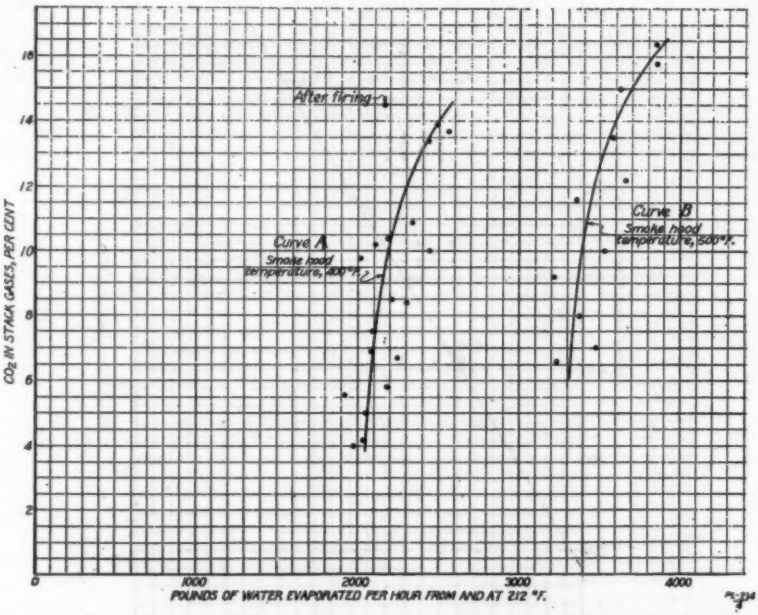

FIG. 3. RELATION BETWEEN STEAM OUTPUT AND CO_2 PER CENT IN STACK GASES WITH FIXED SMOKE-HOOD TEMPERATURE IN A STEAM-HEATING SECTIONAL BOILER WITH 32.5 SQ. FT. GRATE AREA. THE OUTPUTS FOR THE 400 DEG. FAHR. TEMPERATURE WERE INSTANTANEOUS STEAM FLOW BY ORIFICE METER. FAIRMONT COKE USED. THE OUTPUTS FOR THE 500 DEG. FAHR. TEMPERATURE WERE THE AVERAGE OVER 10-MIN. PERIODS. SEARIGHT COKE USED

keep the rate of feed constant during the short periods of observation, calibrated orifices were inserted in the feed line of each boiler and connected to mercury manometers.

The rates of output for the short periods were determined from the steam. The steam pipe of the large boiler was equipped with a thin plate orifice, and readings were taken every 15 or 30 seconds during the observation period. The steam from

the small boiler was condensed and weighed; the condenser was of such a type, and was so mounted, that the condensate would drain immediately.

Copper-constantan couples were used to measure the flue-gas temperatures and the Tentative Rating Code instructions were followed in their assembly and in their mounting in the stack. A duplicate couple was available and was inserted into the stack twice during each test to check the other. The opportunity was taken to find how far the code instructions ensured the same temperature over the cross-section of the flue pipe, and the spare couple was used to make a survey. The greatest difference of temperature noted for any portion of the 30-in. pipe of the large boiler was 3 deg. fahr., and this difference was only momentary, demonstrating that the construction specified ensured adequate mixing of the gases, and that the insulation up to the damper is effective.

Considerable experimentation was necessary to acquire the correct technique, particularly in the handling of the fuel bed, to have it in a similar condition for consecutive readings. Coke was mostly used because it gives a more uniform bed, and a given fuel bed condition is more easily duplicated.

Relation of Steam Output to Smoke-Hood Temperature

The flue-gas temperature is easy to measure and should be a useful indication of the rate of output if a definite relation between them were established. The preponderance of published tests and the performance charts issued by manufacturers show the plot of flue-gas temperature against output to be a straight line, but a large number of other charts show irregular curves. The drop in temperature of the gases between the surface of the fuel bed and the smoke hood is dependent on the laws of heat transfer and can be computed for their relative values for different rates of burning, provided that their initial temperatures could be correctly assumed. The heat absorbed by the boiler is that taken from the gases plus that radiated from the surface of the fuel bed and conducted from the bed to the fire pot. Although these could also be computed, data for the assumptions that would have to be made are so meager that it is preferable to depend upon test results.

During these tests the percentage of CO_2 in the flue gas was maintained approximately constant, at 12 per cent, because at that time the effect of varying CO_2 was not known.

Fig. 1 shows the results obtained with the large boiler. The dots represent the values for one-minute observations. If they were numbered in the order in which they were taken they would show three up and down runs. Some of the dots fall appreciably off the mean straight line, but this test occurred early in the series, before the best technique was developed; the coke used formed a bad sheet clinker over the grate, and as the observations extended over a period of five hours there was an appreciable change in the fuel-bed conditions. A one-minute period was not long enough, and the clinkering was so bad that the draft available could not raise the temperature above 650 deg. fahr., whereas with other cokes 800 deg. fahr. was obtained.

In spite of this the test points give a consistent straight-line relation, and this line extended crosses the temperature axis at 150 deg. fahr.

Fig. 2 shows the results for the small boiler. These observations covered 10-min. periods and there was better control. The straight line extended meets the axis

at 180 deg. fahr. Points *R*21 and *R*26 are the average values for four-hour tests made at other times. A line through them also intersects at 180 deg. fahr.

Tests not reported showed that the straight-line relation was true only if the fuel-bed condition was approximately the same during each observation. In the large boiler this is not so important because the rate of burning soon brings the bed to the same surface condition. In the small boiler, however, it takes longer, and a test similar to that in Fig. 2, but with bituminous coal, gave points with considerable variation from the mean line.

The proposed code is not so much concerned with instantaneous values as it is with the mean during a complete test, and during that period the fuel bed will have gone through similar cycles of conditions in each test.

The intersection of the mean line with the temperature axis is important. Actually, the temperature of the flue gases could never go below that of the boiler surfaces which, if the steam pressure were kept up, might be 215 deg. fahr. The operation of a boiler at very low rates has no particular interest, at least for the purpose of the code, and the point of intersection of the straight line through the higher values is required. Available performance charts of other boilers indicate that 175 deg. fahr. is a safe average value to use if complete data for a particular boiler are not available.

It can therefore be concluded that if one complete test is made at high rating and the average flue-gas temperature and rate of output are plotted on a performance chart, then a straight line through this point and 175 deg. fahr. on the temperature axis will give the flue-gas temperature at other outputs; also, these values thus predicted will be safe within the order of accuracy required for the purposes for which they will be used.

Relation between Output and CO_2 Content of the Flue Gas with Smoke-Hood Temperature Constant

Not much information was available on the relation between output and CO_2 content of the flue gas with smoke-hood temperature constant. Its consideration is more complex than was the output-temperature relation, since the causes for the change in CO_2 content must be included. The lowering of the CO_2 because of infiltration of air behind the boiler is excluded, but with many boilers all filtration cannot be prevented, even with the best of care. Low CO_2 may result from a thin fuel bed, holes in it, fuel pieces being too large, or from too much excess air being admitted over the fire. The results also partly depend upon how the air is admitted. One way is to leave the ashpit door wide open and admit air more freely above the fire by using the fire-door slots to the full or by partly opening the door itself; with this method the ashpit pressure remains zero and the draft through the boiler kept to the minimum. The other method is to use only the door slots, and if more air is required through them than they will draw in with the slots wide open, then partly close the ashpit door, thus creating a greater draft over the fuel bed; this means a greater draft all through the boiler and proportionally more air infiltration through clean-out doors or other places.

The large boiler had the customary slots in the firing door, but in addition it had means of admitting air beyond the firing bed so that combustion could occur in the combustion chamber. Fig. 3 shows the results obtained with this boiler in two

separate tests. Curve *A* represents the first test when the flue-gas temperature was maintained at 400 deg. fahr. For the majority of the points air was admitted at the back, but the slots were used for some. The ashpit door was adjusted to

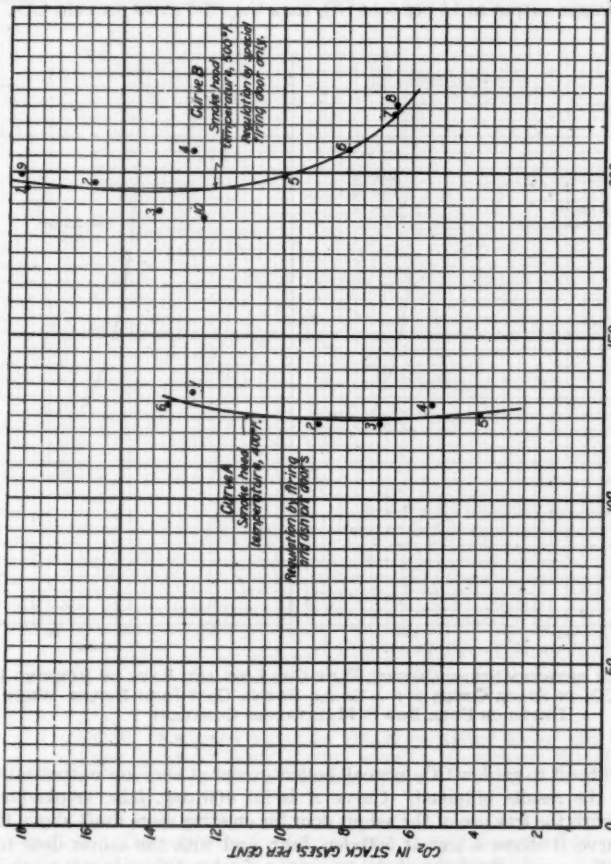

FIG. 4. RELATION BETWEEN STEAM OUTPUT AND CO_2 PERCENTAGE IN STACK GASES WITH FIXED SMOKE-HOOD TEMPERATURE IN A ROUND CAST-IRON STEAM-HEATING BOILER HAVING 3.14 SQ. FT. GRATE AREA. THE OUTPUTS WERE OBTAINED BY CONDENSING THE STEAM. COKE USED FOR FUEL. NUMBERS INDICATE THE ORDER IN WHICH OBSERVATIONS WERE MADE

obtain the low CO_2 values. The departure of the points from a mean curve is due to lack of uniformity in method of manipulation.

In the test corresponding to Curve *B*, Fig. 3, the ashpit draft was kept zero and only the back damper used; the fuel bed was maintained at 12 in. in thickness, with the result that 6.2 per cent was the lowest CO_2 obtainable. It would have been

more correct to plot two curves from the points, as the outer and inner set represent values as the CO_2 was run by steps up and down, respectively.

These two curves are of the same general shape and show that the rate of outputs were the same up to 10 per cent CO_2; then they gradually increased and gave a 10 per cent larger output at 16 per cent CO_2 than they did at 10 per cent CO_2.

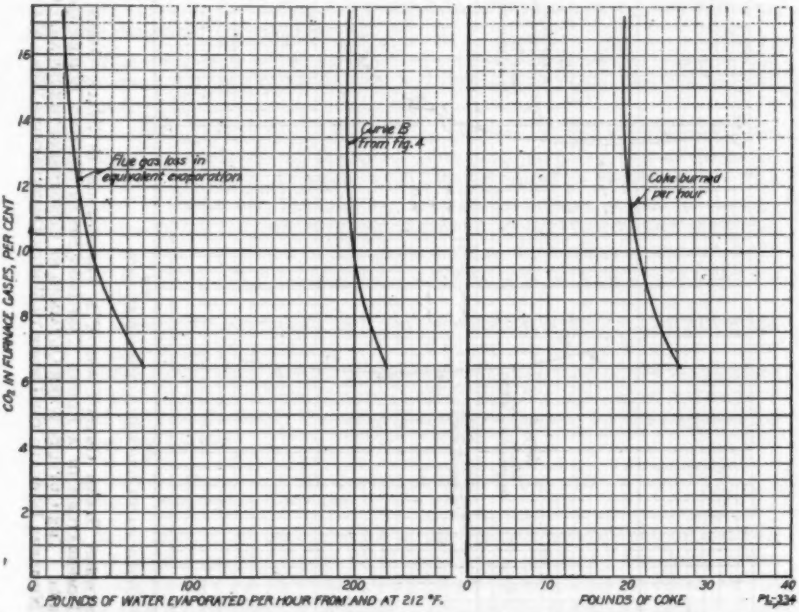

FIG. 5. RELATION BETWEEN STEAM OUTPUT, FLUE-GAS LOSS AND RATE OF BURNING FUEL AND PER CENT CO_2 IN STACK GASES FOR A SMALL ROUND CAST-IRON BOILER WHEN THE DEPTH OF FUEL BED IS MAINTAINED CONSTANT

It is more difficult to get low CO_2 in small boilers except at very low output rates. Fig. 4 shows the results obtained. Curve *A* is for 400 deg. fahr. smoke-hood temperature, with the free use of the ashpit door for creating more draft above the fuel bed. Curve *B* shows a test at 500 deg. fahr. and with the ashpit door full open. The difference in the shape of the two curves for low CO_2 values is marked, and was caused by the method of admitting the air. High draft was required to obtain the rate of burning with the ashpit closed, and the operation of this boiler at the low CO_2 values was abnormal for both tests.

The study of the relation between steam output and CO_2 content should be extended, but the results presented show that the output within the range of limitations set up by the tentative code is not appreciably affected by the per cent CO_2

in the flue gases. The draft required and the efficiency obtained do, however, depend upon the CO_2 content, that is, the excess air.

The loss in the flue gas increases as the CO_2 decreases. Fig. 5 illustrates this graphically. The middle curve is a duplicate of Curve *B*, Fig. 4, and shows the steam output plotted against CO_2 content. The curve on the left shows the dry

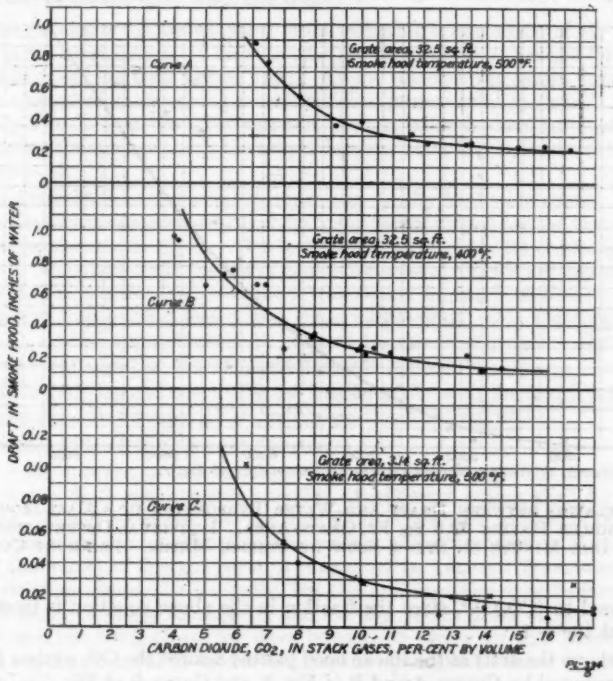
Curve A
Grate area, 32.5 sq. ft.
Smoke hood temperature, 500°F.
Curve B
Grate area, 32.5 sq. ft.
Smoke hood temperature, 400°F.
Curve C
Grate area, 3.14 sq. ft.
Smoke hood temperature, 600°F.
DRAFT IN SMOKE HOOD, INCHES OF WATER
CARBON DIOXIDE, CO2, IN STACK GASES, PER CENT BY VOLUME

FIG. 6. RELATION BETWEEN DRAFT IN SMOKE HOOD AND PER CENT CO_2 IN FLUE GASES WITH A CONSTANT FLUE-GAS TEMPERATURE

flue-gas loss. The curve on the right is the corresponding rate of burning the fuel. These curves show the rapidly increasing loss due to low CO_2.

Relation of Draft to CO_2 Content of Flue Gas

The chimney draft required to obtain a given output increases rapidly with decrease in CO_2 content and the approximate relation between these quantities can be deduced as follows. The weight of gases passing through the boiler per pound of carbon burned can be expressed by

$$W_s = \frac{3.032\,N_2}{CO_2 + CO} + 1$$

The drop in pressure through the boiler, with constant average temperature, would be of the order of $(W_s)^{1.8}$, and consequently the drop in pressure with constant load and constant average temperature of the gases should be approximately

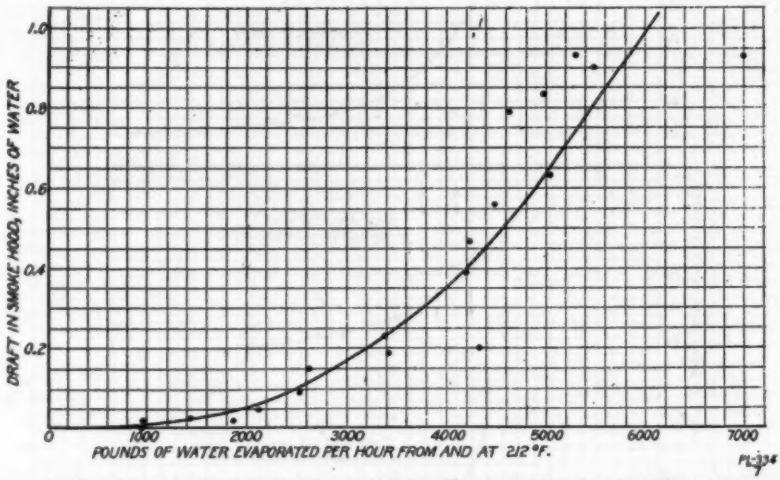

FIG. 7. RELATION BETWEEN DRAFT AND WATER EVAPORATED IN A CAST-IRON STEAM-HEATING BOILER HAVING 32.5 SQ. FT. GRATE AREA. INDIVIDUAL OBSERVATIONS WERE MADE FOR ONE MINUTE ON STEAM FLOW BY ORIFICE METER. FAIRMONT COKE USED

proportional to $(CO_2)^{-1.8}$, since the fraction in the above equation is large compared with the + 1.

Fig. 6 shows the draft at the smoke hood plotted against the CO_2 content for the tests represented by Curves *A* and *B* of Fig. 3, and Curve *B* of Fig. 4. In all of these tests the ashpit draft was zero. The drafts as measured in the smoke hood are the apparent drop in pressure due to the resistance to the flow of the gases through the fuel bed and boiler; the observed draft should be increased by the temperature head due to the hot gases to obtain a true measure of the total resistance. For the large boiler the quantity to be added would be negligible compared with the drop due to the resistance to flow, but for the small boiler it would be appreciable.

The draft proportional to the $(CO_2)^{-1.8}$ equation fits Curve *B* of Fig. 6 exactly, and the other two approximately, if the base line of Curve *C* is moved down 0.015 in. to allow for the temperature head.

The increase of draft with decreasing CO_2 is noticeable. The draft necessary with 6 per cent CO_2, from Curve *B*, is $4^1/_2$ times that necessary with 14 per cent.

On the other hand, the difference in draft requirements above 12 per cent CO_2 is not great. It can, therefore, be concluded that if the drafts required by different boilers are to be comparable, then a code is fully justified in placing limitations on the percentage of CO_2 which is permissible in tests to determine operating characteristics.

Relation between Smoke-Hood Draft and Output

Performance charts for boilers show more variation in the shape of the draft than any of the other curves. This is to be expected, because no method for regulating the dampers has been agreed upon. At one extreme, the ashpit damper is kept wide open at all rates, giving a draft which is proportional to (load)^n, where n is usually 2 to 2.5; at the other extreme, the regulation is done automatically by a pressure regulator operating the ashpit damper, when the draft curve may be nearly horizontal.

In these investigations the ashpit damper was usually kept wide open. Fig. 7 shows the relation between smoke-hood draft and steam output for the test of the large boiler represented in Fig. 1. This test was not an ideal one for obtaining consistent draft values because of the heavy clinker formation. The lower draft at the test point for the greatest load was due to the clinker having been broken up to permit the high load being obtained with the available draft; also, there was 15.5 per cent CO_2 against approximately 12 per cent for the other points. The mean curve drawn fits an equation of draft proportional to (output)$^{2.6}$.

The plot or draft against output for the smaller boiler with the ashpit pressure maintained normal fits an equation of draft proportional to (output)$^{2.3}$.

Code Regulation of Draft Requirement Statements

It is an open question as to what regulations should be inserted into a code to ensure that the draft requirements specified for different boilers shall be truly comparable. It will be agreed that the only draft of practical interest is that required at maximum output, also that the corresponding temperature of the flue gases and the weight of flue gas per unit time must be known. From these the necessary chimney size can be computed, but this minimum size must be increased by using a factor of safety to allow for the use of a poorer grade of fuel, for the boiler passages not being clean, for there being more excess air and possibly to allow for air infiltration due to deterioration of the setting with time.

For general use the draft requirements are and should be expressed as the necessary chimney size. The rules for determining chimney sizes are sufficiently indefinite that it is doubtful if the relative draft requirements of boilers can be closely compared from the chimney sizes specified. A purchaser of a boiler might call for the performance charts if they are available, but he should have the assurance that the draft curves are comparable, and a manufacturer should have the necessary guidance to insure him against a disadvantage caused by the manner in which his tests were conducted.

The fuel-bed resistance offers the major portion of the resistance in small boilers and gradually becomes less important as the size increases. In order to insure comparable values for fuel-bed resistance, as determined by tests, the fuel used should be of the same size and have the same clinkering characteristics, and the quantity fired and the cleaning should be regulated. It is then a question whether

TABLE 1. MAIN RESULTS OF RATING TEST OF LARGE CAST-IRON SECTIONAL BOILER (32.5 SQ. FT. GRATE AREA)

Item	Description	Test No. 2	3	4	5	6	7
6	Kind and size of fuel	Clairton coke, stove size	Clairton coke, stove size	Anthracite, nut size	Pittsburgh run-of-mine	Pittsburgh slack	Hazlewood coke, egg size
7	Total weight fired in official test, lb.	1950	1950	1950	1925	1885	1950
8	Time of official test, hrs.	3.25	4.0	4.0	4.0	4.5	4.0
13	Average smoke-hood temperature, ° F.	726	726	706	709	688	723
14	Average smoke-hood draft, inches of water	0.84	0.92	1.00	0.69	0.98	0.70
	Flue-gas analysis, per cent:						
15	CO_2	13.4	12.1	12.4	10.8	10.1	12.7
16	CO	0	0	0	0	0	0.1
17	O_2	7.2	8.4	7.8	8.7	9.1	8.9
23	Water fed, lb./hr.	4489	4493	4123	3863	4348	4201
24	Equivalent output per hour, B.t.u.	4,748,000	4,743,500	4,537,200	4,223,850	4,904,770	4,636,300
25	Average moisture in steam, per cent	0.1	0.4	0.1	0.2	1.1	1.4
—	Rating in sq. ft. of steam radiation*	19,785	19,765	18,910	17,600	20,520	18,470
—	Ratios of rating outputs	1.0	1.0	0.96	0.89	1.03	0.935

* Reduced to the common basis of the output at 700 deg. fahr. flue-gas temperature.

its resistance at the beginning, at the end, or an average over the whole firing period should be used.

Relation between Output and Fuel Used with the Same Average Stack Temperature

A limited number of tests were made according to the Tentative Rating Code of 1927 to determine what effect the fuel used would have on the output. These tests could not go very far in the time available, but the main items of the results obtained are given in Table 1 for the large boiler, and in Table 2 for the small boiler. The code instructions were followed closely. Both boilers were re-cemented between sections before the tests were started.

For the information of those not familiar with the A.S.H.&V.E. Tentative Rating Code of 1927, it may be stated that it specifies that the average flue-gas temperature shall not exceed 700 deg. fahr., the moisture in the steam not greater than 2 per cent, and the percentage of CO_2 in flue gases not less than 12 for coke and anthracite and 10 for bituminous coal. These tests aimed at obtaining the maximum allowable output.

Table 1 gives the results of six tests on the large boiler in which five different fuels were used. Test 2 used stove size coke but an accident prevented it being continued the full four hours. Similar coke was used in Test 3 and it is interesting

that the rated output obtained was almost exactly the same as for Test 2. Such close agreement could not usually be expected.

The relative outputs given by the fuels used are stated in the bottom line of Table 1. It should be remembered that they are relative outputs with the same average temperature of the flue gases. These outputs are as follows:

Fuel and size	Ratios of rating outputs
Clairton coke, stove size	1.0
Anthracite, nut size	.96
Pittsburgh bituminous, run-of-mine	.89
Pittsburgh bituminous, slack	1.03
Hazlewood coke, egg size	.935

The most interesting fact is that the bituminous slack gave a higher output than the run-of-mine coal. Several explanations could be advanced, but they have not been proved. The slack required more attention to the fuel bed; consequently its surface may have been kept broken up and transmitted more radiation. The high resistance of the fuel bed would, for the same rate of output, tend to

TABLE 2.—PRINCIPAL RESULTS OF RATING TESTS OF A ROUND CAST-IRON HEATING BOILER (3.14 SQ. FT. GRATE AREA)

Item	Description	Test No. 16	21	22	23	25
6	Kind and size of fuel	Clairton coke, domestic size	Lowell coke, 1½ to 2 in.	Anthracite, 1½ to 2 in.	Pittsburgh coal, ½ to 2 in.	Pittsburgh coal, ½ to 2 in.
7	Total weight fired in official test, lb.	63	98	64	32	59
8	Time of official test, hrs.	4	4	4	4	4
13	Average smoke-hood temperature, ° F.	706	715	706	706	706
14	Average smoke-hood draft, inches of water	0.14	0.10	0.08	0.06	0.03
	Flue-gas analysis, per cent:					
15	CO_2	12.8	11.9	13.4	12.9	11.0
16	CO	0	0	0.3	0.6	0.5
17	O_2	7.5	8.8	6.5	6.0	8.1
19	Steam condensed, lb./hr.	238	271	256	180	159
20	Equivalent output, B.t.u.	264,300	298,000	288,820	202,500	177,840
25	Average moisture in steam, per cent	0.7	1.1	0.6	1.1	0.6
—	Rating in square feet of steam radiation*	1100	1240	1190	844	741
—	Ratio of rating outputs	1.0	1.13	1.08	0.77	0.68

* Reduced to the common basis of the output at 700° F. flue-gas temperature.

produce a relatively higher rate of burning around the sides of the fuel bed, with the possibility of consequent better heat transmission. It will of course be recognized that this higher rate only means the higher rate with the same flue-gas temperature, and not that the slack would be the better fuel. In fact, no higher rate than that obtained was possible with the draft available, whereas a decided increase, but with the corresponding higher flue-gas temperature could have been obtained with any of the other fuels.

Table 2 shows the results with the small boiler of 5 tests using 4 fuels. The output ratios were:

Fuel and size	Ratios of rating outputs
Clairton coke, domestic size	1.0
Lowell coke, 1 1/2 to 2 in.	1.13
Anthracite, 1 1/2 to 2 in.	1.08
Pittsburgh coal, 1 1/2 to 2 in.	.77
Pittsburgh coal, 1 1/2 to 2 in.	.68

These results are not very consistent and the number of tests made will not allow reliable conclusions to be drawn. The relative output with the Pittsburgh coal was lower than it was with the large boiler, as would be expected.

Summary and Conclusions

The paper reports a limited number of tests of a large and of a small solid fuel low-pressure steam heating boiler to determine the relation of the rate of steam output to the flue-gas temperature, to the excess air or per cent CO_2 in the flue gas, and to the fuel used; also the relation of smoke-hood draft to rate of output and to per cent CO_2.

The results obtained and conclusions reached are:

1. For a given fuel and for similar firing and attention condition, the plot of smoke-hood temperature against rate of output gave a straight line which intersected the temperature axis for the boilers tested at 150 deg. fahr. for the large, and 180 deg. fahr. for the small boiler.

2. The general truth of this relationship is well confirmed by performance curves of other boilers and it is suggested that a line drawn through the test point at a high rate of output and 175 deg. fahr. on the temperature axis expresses the relationship sufficiently accurately for practical purposes.

3. With a constant stack temperature and similar fuel-bed conditions the rate of output showed no great difference between that with high and that with low per cent CO_2 in the flue gas, and the ratio may be greater or less than unity depending on the type of boiler and method of operation.

4. The stack draft required for a given rate of output increased rapidly with decreasing per cent CO_2 in the flue gas, and the draft measurements obtained in these tests approximated to the theoretical formula—draft varies inversely as $(CO_2)^{1.8}$.

5. With zero ashpit draft and similar fuel-bed conditions the stack draft varied as $(\text{output})^n$, where n was 2.3 for the small, and 2.6 for the large boiler.

Acknowledgments

The tests here reported were made at the Pittsburgh Experiment Station of the U. S. Bureau of Mines. The test work was carried out by C. E. Augustine and B. A. Landry, assisted by Charles Schramm.

DISCUSSION

S. R. LEWIS: I wish to be sure that in the great amount of talking we have been indulging in about cooperative research with universities, we give proper emphasis to the great service which has been rendered to us by the United States Government. It was only through the cooperation of the U. S. Bureau of Mines that we were able to start research. They have also furnished us at Pittsburgh with fully as much in the way of cooperation and men and money and space and steam and electricity as we get anywhere. In this present testing of boilers that has just been done the Bureau of Mines has paid all of the cost of the work. Mr. Nicholls is indefatigable in his devotion to our organization and to the Boiler Testing for the Rating Code Committee. We want to be sure to remember that this is the Nicholls of the Nicholls Heat Meter of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

We are promised further cooperation from the Government and, if necessary, the carrying out of further tests in connection with the development of this code.

PRESIDENT ANDERSON: Any further discussion on Mr. Nicholls' paper?

H. E. LONGWELL: I would like to ask what is the significance of Item 7 in the code for rating tests. This is a statement of the number of pounds of fuel fired during the test and bears no relation to the number of pounds burned. At first sight this is apt to be confusing as one naturally associates the quantity of fuel fired with the quantity burned. When I first glanced over Table 2, giving the principal results obtained with a 24-inch round boiler, I was confounded by the apparent evaporation of 16 pounds of water per pound of anthracite and 22½ pounds of water per pound of Pittsburgh coal, test No. 223. As long as we do not care about the amount of coal burned during the test I think it would be best to ignore the amount actually fired. If the fire had been brought to its best condition just before the beginning of either of these tests it should have been possible to complete the test, especially the test with anthracite, without replenishing the fuel at all.

I would ask if Mr. Nicholls would object to telling us the number of sections in this round boiler between the fire-pot and the dome. Of course, if a fire-pot has a crown sheet, that is equivalent to one section. If there are three sections it is interesting to note that under the code committee's definition of rating, these tests justify the highest ratings that the most optimistic manufacturer would ever put on cast-iron heating boilers. Irrespective of the results shown on the rating test, a load of 475 feet of direct radiation is about the maximum that could be carried in actual service with sufficient ease to satisfy a reasonable house owner. This load could be carried with substantially the same degree of ease by any other round boiler, with the same grate area and the same number of sections between the fire-pot and the dome, by whomsoever made, regardless of the result shown on a rating test of this character.

P. NICHOLLS: Mr. Longwell has misunderstood the meaning of Item 7 of the table. The caption defines it as the total weight fired in official test time, and it is inserted to show that the tester has fulfilled the requirements of the code. It would be incorrect to use this weight to compute the evaporation per pound of coal.

The paper states that the work reported was investigative. The ratings given

are the outputs obtained when the boilers were tested following the code specification. The direct radiation load which they can carry is not fixed by the rating code but should be settled by the code for selection.

MR. LONGWELL: Will you tell me how many sections there were between the fire-pot and the dome in that round boiler?

MR. NICHOLLS: The number of sections between the fire-pot and dome of the small boiler was two.

No. 798

THE VALUE OF EXTENDED HEATING SURFACES

By C. S. Sage, Fairfield, Conn.
NON-MEMBER

Acknowledgment

The author is indebted to W. H. McAdams and S. D. Turner of the Massachusetts Institute of Technology, Cambridge, Mass., for suggestions, data and sketches submitted in a written discussion of this paper, which was published in the Journal of the American Society of Heating and Ventilating Engineers, April, 1928, page 385, and which was used as the basis for revising the original text.

RECENTLY there have appeared in the house-heating field diverse forms of apparatus destined to supplant the cast-iron radiator, familiar to generations, which employ in addition to primary, direct or wet surfaces a certain amount of extended, secondary, indirect or dry surfaces intended to transfer heat from the hot water, steam or vapor to the air.

Extended or secondary surfaces, comprising all air-exposed surfaces the points of which are farther away from the heat-carrying medium (steam or hot water) than the average thickness of the metal whose boundaries they are, are of course no new conception in the art of transferring heat. They have been used in the shape of ribs, pins and knobs on cast-iron radiators generations ago and also in connection with pipe coils, but it has remained for the advent of the non-ferrous radiator to accentuate their usefulness and importance and to bring them into prominence again.

The reasons for their application with copper and brass radiators are easily discernible. In order to compete with the cast-iron radiator the non-ferrous radiator must show some advantages over the same which may be either price, size, weight, durability, appearance or novel features of heat transmission or distribution.

Certainly if price alone is considered non-ferrous metal cannot be used in the same shape as in cast-iron radiation as its cost pound for pound is probably about 9 to 10 times as much. Besides in the same shape, brass and copper would not show any superiority as far as heat transmission is concerned. By the use of stampings in place of castings the status of the brass radiator could be improved to a certain extent, at least as far as cost and weight are concerned, but not enough to put it into serious competition with cast-iron. Neither as a casting nor as a stamping could the brass radiator show any feature which would rate it higher in heat-transmitting value than the cast-iron radiator and consequently it would be

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of approximately the same bulk as the latter and would have in general the same appearance which admittedly is not prepossessing. Only one advantage would the brass or bronze radiator have over cast-iron, that is its longer life and its freedom from rust. But these advantages weigh very little compared to first cost.

The only points left for an attack on the cast-iron radiator are, therefore, its size and its method of heat transmission, because even its ugly appearance can be tolerated as concealed radiation has made great strides and because many attractive designs of radiator covers have been created in recent years which, although at considerable expense, hide its native homeliness and make its presence endurable even in the most sensitive scheme of decoration.

Reducing the size of a radiator without changing its capacity means that either the transmission coefficient of the reduced heating surface must be increased, or that the same surface must be accommodated within a smaller space, or that surfaces of different character must be employed, which although possibly not very effective per unit area, allow the massing of a large amount of surface within the desired reduced volume.

The *first* of these methods, namely the increase of the transmission coefficient, has been used with cast-iron radiation by the introduction of artificial draft, produced either by mechanical means or by a stack.

The *second*, the disposition of the original heating surface within a reduced volume, has been accomplished by the production of cast-iron radiators with small columns and enlarged internal airways.

The *third*, the application of a surface of a different nature, has been seized upon by the non-ferrous radiator and has put the latter in a position where the cast-iron radiator cannot follow—at least not until other principles of construction have been evolved for it.

The principal characteristic of this surface to which the name of extended surface has been given, is that it discharges heat to the air from every one of its surface points and receives heat usually only through the narrow edge of an aperture provided for the reception of a container of the heat-carrying medium. In other words it is a thin plate or a plurality of plates strung upon a steam or hot-water pipe of any convenient cross-section. This assembly is really a combination of direct and indirect or extended surfaces, as the hot-water or steam pipe which carries the thin plates retains all the properties of a primary surface notwithstanding the fact that its chief mission is to provide heat for the extended surfaces mounted on it.

Two conditions are required to move the heat from the primary surface of the steam or hot-water pipe to the extended surface of the thin plates or fins, as they are commonly called. *First*, there must be a path over which heat can travel without too much resistance, and *second*, there must be some inducement for the heat to leave the primary surface. This means that there must be metallic contact between the primary and secondary surface, and the temperature of the secondary surface of the body of which the secondary surface is the boundary must be lower than the temperature of the primary surface.

The amount of heat which will pass from the hot pipe to the fin over this metallic bridge is determined by the following equation,

$$H = A \times (T_s - T_f) \times \frac{1}{L} \times K_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

wherein H denotes the amount of heat units (B.t.u.) passing during a time unit from the surface of the pipe to the fin, A is the area of contact between pipe and fin, T_s is the surface temperature of the pipe, T_f is the temperature of the fin at a distance L from the pipe and K_c is the coefficient of thermal conductivity of the material forming the fin or the connection between fin and pipe.

A numerical example will illustrate the results obtained by this formula (1),

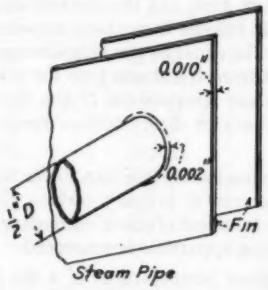

FIG. 1.

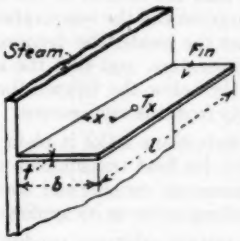

FIG. 2.

and it shall be assumed that the material of the connection between fin and pipe shall possess the same thermal conductivity as the fin and the distance L shall be small compared with the outside diameter of the circular steam pipe. Let the outside diameter of the steam pipe be $^1/_2$ in. and the thickness of the fin 0.01 in. which will make the area of contact A 0.0157 sq. in. The temperature of the fin at a distance of 0.002 in. shall be 1 deg. less than the temperature of the pipe which makes $(T_s - T_f) = 1$. Let the fin be copper, the coefficient of conductivity of which is 19.4 = K_c. Therefore, $H = \dfrac{0.0157 \times 1 \times 19.4}{0.002} = 152.3$ B.t.u. This means that 152.3 B.t.u. pass in 1 hr. from the pipe to the fin under the above stated conditions. This result is, of course, not mathematically exact as the formula holds good only for infinitely small differences of temperature and presumes no external heat loss.

From the structure of equation (1) it is apparent that the amount of heat transmitted depends on the active area of contact, which means that there must be no gap in the girdle around the steam pipe, no holes, no imperfect fit but an intimate, close contact. Furthermore, because the coefficient of conductivity K_c appears as a factor in this equation, the heat delivery is also dependent of the nature of the material which makes the connection. Not only must this material have high conductivity but it also must be permanent, that is, corrosion must not take place and impede or interrupt heat transmission.

The heat now safely landed on the fin will spread through its body and at the same time the air will abstract some of it from the exposed surface.

The process of distributing the heat through the material of the fin is governed by the same laws of conductivity which have been explained above, that is, there must be a path and a difference in temperature to make the heat move. There is of course no question about the path—that is provided by the homogeneous material of the fin. The required difference of temperature, however, can only be maintained by a constant loss of heat to the air which necessitates a constant air current. It is therefore evident, that the temperature of the fin cannot be uniform because not only is it necessary that the outer edges be cooler than the portions which are nearer to the source of heat, the steam pipe, but the surfaces must also be cooler than the interior of the fin body. It follows from these considerations that at no point can the temperature of the fin be equal to the temperature of the steam, that the greater the distance of a point from the steam pipe the lower will be its temperature, and that the average surface temperature of the fin will be considerably below the temperature of a primary or direct surface receiving its heat supply from the same source.

These deductions make it plain that the extended surface can never have the same value for heat transmission as the same area of primary surface, that this value is moreover variable and that the mere statement of size of secondary surface means nothing as far as its application in heating apparatus is concerned.

Under certain arbitrary conditions the surface temperatures of a fin may be determined by the application of a formula given substantially as in its present shape by J. Fourier in his Theory of Heat many years ago, which is expressed as follows:

$$T_x = T_0 e^{-mx} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

wherein $m = \sqrt{\frac{K_r p}{K_c s}}$, and K_r is the transmission coefficient of the surface, p the perimeter of the fin section, K_c the coefficient of conductivity of the fin material, s the area of the cross-section of the fin, e the base of the natural or hyperbolic logarithms, x the distance of the point of which the temperature is sought from the source of heat, and T_x the temperature difference between metal and air at this point, and T_0 the temperature difference between metal and air at the source of heat.

This formula is applicable only under the following conditions:

(1) The fin is connected to the source of heat only along one long edge,

(2) The thickness of the fin is small compared to its length,

(3) The temperature of the cooling air is constant and uniform all over the surface of the fin.

(4) The length b of the fin is infinite.

A design of an assembly of this kind is shown in Fig. 2.

As an illustration, a numerical example may be considered in which K_r = 1.5 B.t.u. per sq. ft. per hr. per 1 deg. difference in temperature, K_c = 19.4 B.t.u. per

hr. per sq. in. per inch per 1 deg. difference in temperature between faces, and where the thickness of the fin is 0.01 and 0.02 in., respectively.

With temperature differences T_s of 145 and 100 deg., respectively, and with an air temperature of 70 deg., the real temperatures t_x at a point at a distance x from the source of heat are as shown in Table 1.

TABLE 1. NUMERICAL VALUES OF CURVES SHOWN IN FIG. 3

x in Inches	t_x'			
	$T_s = 145$, $t_s = 215$		$T_s = 100$, $t_s = 170$	
	$t = 0.01$ in.	$t = 0.02$ in.	$t = 0.01$ in.	$t = 0.02$ in.
0.05	212.6	213.4	168.3	168.9
0.10	210.3	211.7	166.6	167.7
0.15	208.1	210.1	165.2	166.6
0.20	205.3	208.5	163.7	165.5
0.25	203.6	206.9	162.2	164.4
0.30	201.5	205.3	160.7	163.3
0.35	199.3	203.7	159.2	162.2
0.40	197.2	202.2	157.7	161.2
0.45	195.2	200.7	156.3	160.1
0.50	193.1	199.2	154.9	159.1

A chart of the values in Table 1 is shown in Fig. 3.

A different result follows if a fin of finite length is considered for which case a formula has been developed by W. H. McAdams and S. B. Turner from the deriva-

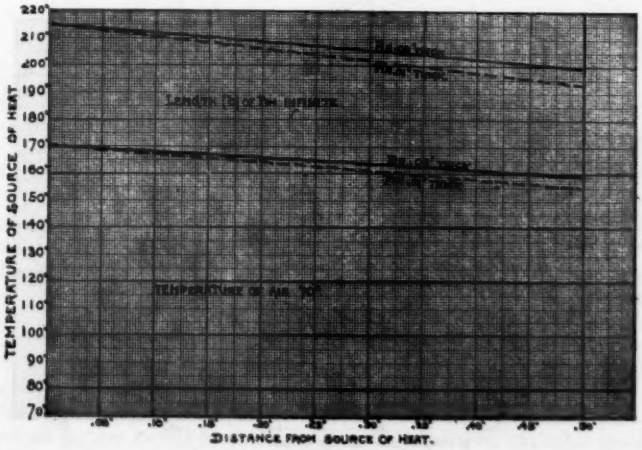

FIG. 3. TEMPERATURES AT VARIOUS DISTANCES FROM SOURCE OF HEAT FOR FIN OF INFINITE LENGTH

tions published by S. R. Parsons and D. R. Harper in their paper on *Radiators for Aircraft Engines* prepared for the *U. S. Bureau of Standards.*

This formula is expressed as follows:

$$\frac{T_x}{T_s} = \frac{\cosh m\,(b - x)}{\cosh mb};\ m = \sqrt{\frac{K_r p}{K_c s}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

wherein all symbols have the same meaning as in formula (2) and where b is the extension of the fin from the source of heat.

TABLE 2. NUMERICAL VALUES OF CURVE SHOWN IN FIG. 4

x in Inches	t_x $T_s = 145$ $t_s = 215$ $t = 0.01$ in.
0.10	214.4
0.20	213.8
0.30	213.4
0.40	213.2
0.50	213.1

Numerical examples of the application of this formula are given in Table 2 and a chart of these values is shown in Fig. 4.

These curves show very clearly how the surface temperatures decrease with the increase of the distance from the source of heat and how the thickness of the fin affects the distribution of heat. It is curious to note that the beneficial

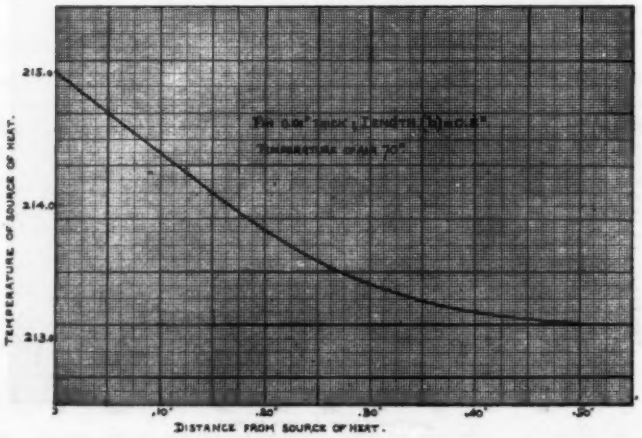

FIG. 4. TEMPERATURES AT VARIOUS DISTANCES FROM SOURCE OF HEAT FOR FIN OF FINITE LENGTH

influence of a thicker fin is the more marked the farther away from the source of heat the temperature is observed.

In a similar way, and in fact based upon these calculations, it has been possible to develop a formula for the efficiency of extended surfaces. This formula has been used by S. R. Parsons and D. R. Harper in their researches on Radiators for Aircraft Engines previously mentioned and is written as follows:

$$E = \frac{tanh\ (u)}{u} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

wherein $u = b\sqrt{\frac{2K_r}{tK_c}}$, and E the efficiency of the extended surface, $tanh\ (u)$ the hyperbolic tangent of u, b the width of the fin, K_r the transmission coefficient of the standard surface, t the thickness of the fin and K_c the conductivity of the fin material.

This formula is applicable only under the conditions named for the temperature equations (2) and (3).

Numerical examples worked out for the same fin characteristics as previously cited and for fins from $^1/_2$ to $2^1/_2$ in. wide give the results shown in Table 3.

TABLE 3. NUMERICAL VALUES OF CURVES SHOWN IN FIG. 5

Width of Fin $-b$ in Inches	E in Per cent	
	t = 0.01 in.	t = 0.02 in.
0.5	98.5	99.6
1.0	96.5	98.2
1.5	92.7	96.1
2.0	87.8	93.4
2.5	82.3	90.2

Fig. 5 shows the graphic results given in Table 3.

The temperature does not appear as a factor in this equation and consequently the efficiency of an extended surface is not affected by the operating temperature, which sounds strange, but it is to be remembered that this efficiency is merely a comparison with a wet surface of the same temperature and is not to be confounded with the transmission coefficient which changes with the temperature.

These theoretical investigations are very interesting and certain relative deductions can be drawn from them, as for instance the influence of the thickness of the fin, but for an exact predetermination of results these calculations are of little value for the reason that too many assumptions have to be made, assumptions which under actual working conditions never materialize. For instance it is assumed that the temperature of the air which touches the fin is the same over the whole surface, which under house-heating conditions is impossible, as the air entering from below naturally gets warmer the higher it rises along the fin; it is further assumed that the transmission coefficient is constant, which is not the case in actual service as will be shown later. It is, therefore, advisable to exert great caution whenever these equations are used.

It is surprising to see how many forces affect the performance of an extended

surface and in the following paragraphs an attempt will be made to consider these factors individually and to show their influence.

Three simultaneous equations exist concerning the heat transfer in this process:

The heat transmitted to the air by convection H_a must equal the heat lost by convection by the radiator H_r and must be equal to the latent heat of the condensed steam multiplied by the convection factor of the radiator K_r. The convection factor K_r being the percentage of heat abstracted from the radiator by

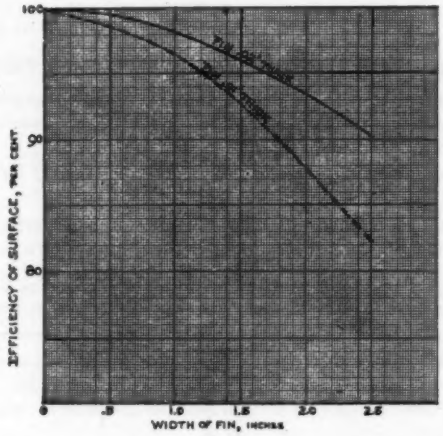

FIG. 5. CURVES SHOWING VARIATION IN EFFICIENCY OF SURFACE WITH WIDTH OF FIN

convection only, the balance of the liberated heat being, of course, dispersed by pure radiation.

These three simultaneous equations can be expressed algebraically as follows:

$$H_a = H_r = w \times r \times K_r \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

wherein w is the weight and r the latent heat of the condensed steam.

Now H_a is proportional to the weight of the air and to the difference in its temperature before and after it has been in contact with the radiator. Therefore, H_a is a function of weight w_a and temperature t_1, t_2 of the air, *viz:*

$$H_a = f[w_a\ (t_1 - t_2)] \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The heat lost by convection by the radiator H_r is proportional to the exposed area A of the radiator, to the difference between the average temperatures of the surface of the radiator and of the air $(T_r - t_a)$, and to the transmission coefficient K_r, *viz:*

$$H_r = f[A\ (T_r - t_a),\ K_r] \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

In equation (6) the weight of the air w_a is mentioned and in this connection

the following deduction is apparent. The weight of the air, which during a time unit passes along a heated surface, is directly proportional to the velocity of the air flow and inversely proportional to the amount of friction which the air stream encounters on its travel along the heated surfaces. In natural, unassisted circulation the motive power, which creates this circulation, is the difference in weight of air columns of different temperatures. It is the same force which makes the air go around in a hot-air heating system and the same laws which govern the one will be applicable to the other. In a hot-air system, the more vigorous the circulation,

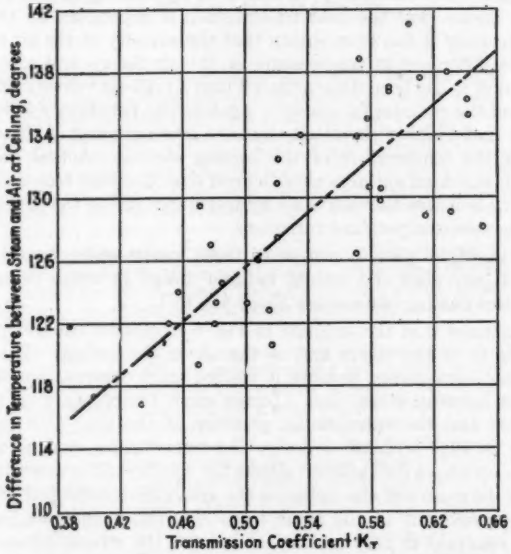

FIG. 6. CURVE SHOWING INCREASE IN TRANSMISSION COEFFICIENT K_t WITH TEMPERATURE DIFFERENCE

the greater the difference in temperature between the ascending and descending air streams and the same presents itself with a radiator.

The amount of friction is directly proportional to the fin area which the air stream has to touch in its passage through the radiator. This means the more fin area per cu. ft. of air flow the larger is the resistance and consequently the smaller the velocity of the air.

This conclusion touches one of the most important points in the use of extended surfaces because it follows from it that the mere massing of extended surfaces, the crowding of a certain given space with fins does not mean a corresponding increase in capacity. In some instances the capacity will even decrease if the reduction of air circulation, due to increased friction, overbalances the gain in fin surface.

The third factor in equation (7) is the transmission coefficient K_r. This coefficient is influenced by two factors. One is the temperature difference between the hot surface and the air, and the other is the velocity with which the air passes along the hot surface. The latter is very powerful for the following reason.

It has been established by numerous investigations that on any surface along which heat transmission takes place a thin film of the heat-receiving substance is formed which retards to a great extent the passage of heat through it. This film is very tenacious and adheres with considerable force to the hot surface. The only way to get rid of this film is to tear it off by rushing the air past it at high speed, which means that the heat transmission is dependent on the velocity of the air. Previously it has been shown that the velocity of the air stream is controlled by the difference in temperature of the air before and after passing the radiator and now it has been demonstrated that a high air velocity affects the heat transmission of the radiator favorably. Against this beneficiary influence it must be considered that a higher air velocity means a larger amount of air and this causes a lowering of the temperature of the heating surface. Actual observations of radiators with extended surfaces show indeed that the heat transmission of these surfaces is very sensitive to relative air temperatures and to the changes of air flow engendered by these temperature variations.

The chart in Fig. 6 gives a picture of these results which have been obtained by tests of different sizes of a certain radiator design in which the proportion of indirect to direct heating surface was about $4^1/_2$ to 1.

It will be noticed that the ordinate in Fig. 6 represents the difference between the temperatures of the steam and of the air at the ceiling. This standard of comparison has been chosen because it yielded more coherent results than either the difference between steam and average room temperature or the difference between steam and the entrance temperature of the air. One reason for this circumstance is that without a doubt the temperature, and consequently the density of the air above the radiator, affects the velocity of the ascending air stream. The height of the room will also influence the heat transmission but for comparative experiments carried out in the same room this factor remains constant. The slope of the resultant is very marked and shows the strong influence which the temperature of the air has on the heat transmission.

It is well to remember, however, that these results have been obtained from, and are consequently valid for only one particular type of extended surface radiation. Other fin arrangements will have different characteristics, and general conclusions should not be drawn until a fairly large number of tests of different designs have been made.

In all preceding calculations only the heat which has been transferred to the air by convection has been considered. It is one of the main characteristics of the different types of non-ferrous radiators using extended surfaces that the proportion of the heat abstracted by convection to the heat lost by radiation is very large, much larger than with cast-iron radiation, which fact is explained by the lower temperatures of the extended surfaces and also by the arrangement of these surfaces which in most cases effectively screen any direct radiation. The absence of the stinging heat rays so painfully noticeable with cast-iron radiation is a fact easily detected when in close proximity to an extended-surface radiator.

No. 799

STANDARD TEST CODE FOR HEAT TRANSMISSION THROUGH WALLS

Preface

A CONSIDERABLE number of methods have been proposed and used for the determination of the heat transmission of building materials and constructions. Owing to this fact, and to some confusion that has existed in the understanding and use of the terms "coefficient of heat transmission" and "coefficient of conductivity," wide variations have arisen in the application of the published laboratory values of these coefficients to actual wall constructions. To further complicate conditions, many of the laboratory values have been determined with temperature ranges and mean temperatures of the materials considerably removed from those to which the materials are subjected in actual use.

This code has not been framed for the purpose of offering detailed instructions for testing the heat transmission of building materials, or for constructing testing apparatus, but rather for defining certain standards, the application of which, it is hoped, will bring the results of different investigations into better conformity than is found at the present time.

In order to obtain complete information on the heat transmission through building walls, two classes of tests must be considered, either one or both of which may become necessary or advisable, depending on the purpose in view. (1) Tests on the conductivity of homogeneous materials must be run in order to determine the fundamental constants which constitute the basis for the calculation of the over-all heat transmission through built-up walls. (2) Tests on the over-all heat transmission through actual built-up walls may be run to serve as a check on the validity of calculated values, or to establish these values in cases where the nature of the constructions does not permit accurate calculations being made. Separate sections of the code have, therefore, been devoted to these two classes of tests.

Committee,

A. P. KRATZ, University of Illinois
G. L. LARSON, University of Wisconsin
J. C. PEEBLES, Armour Institute
F. C. HOUGHTEN, Director Research Laboratory

PART I—DEFINITIONS AND FORMULAS

Definitions and Formulas

(1) The coefficient of heat transmission is the heat transmitted per square foot per degree fahr. difference in temperature between the *air* on one side and the wall to the *air* on the other side per hour.

(2) The surface coefficient is the heat transmitted per square foot per degree fahr. difference in temperature between the *surface* of the wall on one side and the *air* on the same side per hour.

Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

(3) The coefficient of conductivity is the heat transmitted per square foot per degree fahr. difference in temperature from the *surface* on one side of the wall to the *surface* on the other side per hour per inch of thickness. This coefficient is of doubtful significance except in cases of solid walls of homogeneous material.

Let U = coefficient of heat transmission
K_1 = surface coefficient on hot side
K_2 = surface coefficient on cold side
C = coefficient of conductivity
W = Watts electrical input
H = B.t.u. transmitted per hour = 3.4145 W.
A = Area perpendicular to flow of heat, sq. ft.
X = thickness of wall, in.
t_h = temperature of air on hot side, deg. fahr.
t_c = temperature of air on cold side, deg. fahr.
t_1 = temperature of hot surface, deg. fahr.
t_2 = temperature of cold surface, deg. fahr.

Then

$$U = \frac{H}{A(t_h - t_c)}$$

$$K_1 = \frac{H}{A(t_h - t_1)}$$

$$K_2 = \frac{H}{A(t_2 - t_c)}$$

$$C = \frac{HX}{A(t_1 - t_2)}$$

PART II—CONDUCTIVITY OF HOMOGENEOUS MATERIALS

The guarded hot plate shall be the standard method for determining the conductivity of homogeneous materials. This method is not applicable to the determination of over-all heat transmission coefficients. The construction of apparatus, and the procedure recommended by the United States Bureau of Standards, JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 26, No. 7, October, 1920, shall be followed and the temperature of the surfaces of the materials shall be regarded as that of the plates on each side. The test specimen shall be at least 8 in. x 8 in. and the plates must be applied in such a manner that the density and other physical characteristics of the material under test is not altered. Temperature equilibrium shall have been established for a sufficient length of time to insure constant conditions before test data are taken.

In order that results from different laboratories may be comparable, the standard method of making tests shall be at a mean temperature of 60 deg. fahr. and upon dry material. The material shall be dried at a temperature of 220 deg. fahr. for a sufficient length of time to eliminate all moisture before the test is made and the per cent of moisture driven off, together with the atmospheric conditions and the density of the material, shall be reported with the test.

PART III—OVER-ALL HEAT TRANSMISSION

Standard Method of Testing

The standard method of testing shall be by means of the guarded hot box as described by F. B. Rowley in the JOURNAL OF AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 32, No. 5, May, 1926. The standard temperature range from air on one side to air on the other shall be 80 deg. fahr. and the standard mean temperature of the wall shall be 40 deg. fahr. All tests shall be run with still air on both sides of the wall, or the circulation on the inside of the box restricted to an amount just sufficient to obtain uniform temperature throughout. The box shall be under

heat for a sufficient time previous to the start of the test to insure that temperature equilibrium has been attained. The test should continue for a sufficient length of time, and enough observations should be made to present evidence that such temperature equilibrium has been maintained throughout the test, and that the temperature in the space between the boxes has remained the same as that in the inner box. In general the duration of the test should be at least two hours, and need not be more than four hours.

It is strongly recommended that coefficients of heat transmission be obtained with the standard temperature range of 80 deg. fahr. for several mean temperatures of the wall. In all cases both the temperature range and the mean temperature of the wall should be stated in reporting results, and in no case where but one determination is made and reported should the mean temperature of the wall exceed 105 deg. fahr.

Sufficient data should be taken to permit reporting on the surface coefficients for both hot and cold sides of the walls and in cases of walls of elementary materials, the density or weight per cubic foot, and the moisture content shall be stated. Coefficients of conductivity as determined by this method shall not be regarded as the standard coefficients of conductivity.

Construction of Guarded Hot Box

The internal dimensions of the outer box shall be at least 5 ft. x 5 ft. x 5 ft. and those of the inner box 3 ft. x 3 ft. x 3 ft. The walls of the outer box shall be insulated with 3 in. of corkboard, or the equivalent, and the walls of the inner box with 2 in. of corkboard or the equivalent. The wall specimen shall be clamped to the open side of the outer box and in this position must come into firm contact with the edges of the open side of the inner box. These edges shall be thinned down or armoured to insure perfect contact. The air in the inner box shall be heated by means of a resistance coil wound on a cubical frame not to exceed 12 in. on a side, and with characteristics such that the wires or units do not attain a dull red heat, or so shielded that the test specimen does not receive radiant heat from surfaces at a high temperature. The current to the coils both in the inner box and in the space between boxes shall be thermostatically controlled to maintain the same temperature in the inner box and in the space between boxes. Fans shall be installed to maintain uniform temperature in all of these spaces with the minimum circulation of air.

Specimens for Test

(1) The test specimens shall be constructed similarly to actual walls, and not consist merely of plates of the separate materials forming the walls. Such wall specimens shall be constructed to conform to the standard specifications of the manufacturers of the products used, and according to the usual practice of the trade employing average skilled labor.

(2) The portion of the specimen through which the flow of heat is actually measured shall be at least 3 ft. by 3 ft.

Location and Character of Measuring Instruments

All temperatures shall be obtained by means of copper-constantan or iron-constantan thermocouples, and the use of a potentiometer, rather than a galvanometer or milli-voltmeter, is strongly recommended. All couples in the same space with the heating coils shall be shielded against direct radiation from the coils.

The temperature of the air in the inside box shall be obtained by means of four couples placed 6 in. from the inside of the face formed by the test specimen. The surface temperatures of the wall section shall be obtained by means of four couples embedded in each face of the portion of the test wall enclosed within the edges of the inner box. The junctions of these couples and 4 inches of the leads back of the junctions shall be embedded in the surface of the material under test, glued or cemented firmly in place, and filed flush with the surface. One thermocouple shall be placed in the air in each of the air spaces enclosed between the walls of the inner and outer boxes.

Addendum

The Nicholls Heat Meter as described in the JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 30, No. 1, January, 1924, pages 35 to 70, offers a convenient method worthy of consideration for testing actual walls. Since methods for the use of the meter for determining fundamental constants for structural materials have not been well developed, its use as a standard method cannot be adopted at the present date, but since the meter appears to give promise of advantage in making such determinations, it seems well to recognize such possibilities and to recommend that an extensive study be made of its application for the purpose of standardizing its use.

DISCUSSION

M. S. VAN DUSEN (WRITTEN): In the preface to the proposed Code it is stated in substance that the Code has been framed for the purpose of defining certain standards, rather than for offering detailed instructions for the measurement of heat transfer in building materials. It appears to me that this is a desirable thing, but in its present form the Code goes either too much or too little into detail, its exact purposes and limitations are not clearly stated, and no mention is made of the attitude of the Society toward such results as may be obtained in the future by methods and under conditions not considered in the test. I shall endeavor to back up some of these rash statements by more detailed criticism.

In the interest of brevity and definiteness, the section on definitions and formulae might well be omitted and reference made to E. F. Mueller's paper on Definitions, Nomenclature and Symbols, appearing in the 1922 report of the insulation Committee of the *American Society of Refrigerating Engineers*. Mr. Mueller treats the subject much more completely and accurately, his nomenclature is far more logical, and his symbols are probably as good as any other proposed system. In the interest of uniformity it is desirable to have as few different systems of names and symbols as possible. Nothing can be gained by introducing new systems or perpetuating old cumbersome expressions unless it is shown that there is good reason for such action.

The specification of a standard conductivity test on bone dry material at a certain mean temperature is very desirable for certain purposes, but it should be clearly stated what these purposes are. Such a standard test is distinctly advantageous from the point of view of the user who is buying a certain material on a conductivity and weight specification, since tests made from time to time at different places will be exactly comparable, and the user can judge with reasonable certainty whether or not the quality of the product is keeping up to the original standard. The same remarks apply in the case of the manufacturer who has his product tested by laboratories outside of his own organization, and there are, no doubt, other cases where such a proposed test will be advantageous.

On the other hand, however, the proposed standard test as a comparison between two different materials will in many cases be unfair to one or the other. Under normal conditions of use, most materials of the classes in which we are particularly interested contain a considerable percentage of hygroscopic water. A few normally contain practically no water at all. It will be claimed that one material is more affected by the presence of a certain percentage of hygroscopic moisture than another, and there will no doubt be justification for the claim.

It appears that the limitations in the use of the standard test results should be clearly stated in the Code, so that no inferences will be drawn that the standard test is considered to be the correct index of the insulating value of a material under average conditions of use.

As far as details of the standard conductivity test are concerned, there appears to be no particular reason for specifying the exact size of apparatus, any more than there is for omitting the thickness of the test specimen. As a matter of fact, the Bureau of Standards now uses almost exclusively an 8-in. square size, rather than a 12-in., on account of certain experimental advantages. We have also a 24-in. size, and for accurate results it would be necessary to use this large size if we were called upon to test a material which could not be considered homogeneous in a 1-in. thickness, but could be so considered in, say, a 3-in. thickness. Homogeneity is a relative term, and depends upon the size of specimen considered.

In specifying 60 deg. fahr. mean temperature, the idea was apparently to get as near as possible to an average working temperature for insulating and building materials in the heating season. This seems rather futile, since the test of bone dry specimens departs so far from actual conditions of use. As far as this kind of test is concerned, which is more or less arbitrary anyway, some other higher mean temperature would be equally good, in fact better, since the conductivity value obtained would tend to be nearer the true value at 60 deg. fahr. and average moisture content. Experimental difficulty should also be taken into account in a purely routine test. For accurate measurements, a temperature difference of 30 deg. to 40 deg. fahr. is usually required. This would require that the cold water temperature be somewhere in the neighborhood of 40 deg. fahr., requiring refrigeration at most places during part of the year. In summer this temperature is very often below the dew point (practically always in this part of the country) causing condensation on the cold plates and likely to produce errors resulting from condensation in the colder portions of the test specimen. In view of the foregoing, it appears more desirable to raise the mean temperature to 80 deg. or 90 deg. fahr.

It is also obviously desirable to make tests at other mean temperatures and with various moisture contents, but I have been referring thus far only to a single arbitrary standard test made for definite purposes.

Objection might be raised to the method of drying test specimens. It may be argued that the properties of some materials are permanently changed by heating to 220 deg. fahr. This objection can, of course, be overcome by drying specimens in a desiccator at room temperature, but considerably more time would be required.

Referring to the action on overall heat transmission, a few general remarks might be made. The so-called surface coefficients obtained under the laboratory test conditions specified do not appear to be of much significance, particularly the inside coefficient, since the air inside must necessarily be artificially circulated to promote temperature uniformity, a condition vastly different from that normally existing at the inside surface of an exterior wall. The outside (cold side) coefficient as determined may or may not have a relation to the outside coefficient in actual practice. In any case the outside surface resistance of the wall of a building is usually relatively so small and extremely variable that little if any account can or need be taken of it. In view of these facts, effort should be concentrated on the determination of the conductance of the wall itself. In view of the possible

if not probable rapid development of better methods of measuring heat transfer through walls, it may be unwise officially to accept only those results obtained by a specified method and apparatus. Furthermore, one is more apt to place greater confidence in results which have been checked by other methods. The conductance of a certain wall under specified conditions of temperature and moisture content is a definite quantity, susceptible of measurement by more than one method. It is not a purely arbitrary thing, such as for instance the result obtained in a standard pour test for oil. In the latter case, the result is a useful one, but it does not represent any definable property of the oil. It is actually a complicated function of the apparatus and method of procedure as well as of various properties of the oil. In order to get the same result on the same oil, everyone must, therefore, use the specified apparatus and method of procedure. The situation is quite different in dealing with heat transfer through building materials, and it seems unwise indirectly to discourage all methods except one which are different from the one proposed. It does not appear that the situation can be remedied by making a set of hard and fast rules.

PROF. R. W. ANGUS (WRITTEN): The Society is to be commended for its effort to establish a Standard Test Code for Heat Transmission through Walls, and if the Code is properly composed it will prove of great assistance in the laboratories doing such work. One of the purposes of the Code should be to facilitate heat transmission tests, and the conditions laid down should, therefore, be such as can be met by the ordinary laboratory.

It might be advisable to divide the Code into two parts, one dealing with exact results and the other part governing tests giving approximate results within say, 3 or 4 per cent, which would be extremely useful in ordinary building work but might not be good enough for distinguishing between two materials of approximately the same insulating values. These approximate tests could usually be made in much less time than the very exact ones. In this connection, it might be possible to test many homogeneous materials by the hot plate method without the use of the guard ring, where only approximate results are required in very much less time than with the guard ring.

Part 2 of the Code deals with the conductivity of homogeneous materials and prescribes the guarded hot plate for this work, and the apparatus is to be as described in the JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 26, October, 1920. It is presumed that this paper is No. 566 by M. S. Van Dusen in Vol. 26 of the Transactions and if so, this should be stated in the Code. This test should be confined primarily to materials which are used as fillers between two other wall substances, because then the surface resistance does not come into the question and the hot plate method gives the results which would be required in the practical use of the material. Some definition should be given as to what is meant by homogeneous materials.

The specimen recommended is 1 ft. x 1 ft. and the writer would suggest that larger plates, say, 2 ft. x 2 ft. would not only give more accurate average results, but in most cases the error in the coefficient without the use of the guard ring would be very small provided the specimens were not over 1 in. thick and the edges were surrounded with 2 in. of cork board. For instance, if two test specimens 24 in. square and 1 in. thick, and having the same conductivity as cork, are

placed in contact with a hot plate $^3/_4$ in. thick and the edges of the specimens and hot plate surrounded with 2 in. of cork board the heat losses will be relatively very small. Assuming the entire apparatus in a room at temperature 70 deg. fahr. and the temperature of the cold side to be 20 deg. fahr. and that of the hot side 80 deg. fahr., then the heat passing through the specimen will be $60 \times 4 \times k = 240k$ B.t.u. per hr., and the maximum possible edge loss through a surface $^1/_2(1 + ^3/_4) = ^7/_8$ in. x 8 ft. will be $^7/_8 \times ^1/_{12} \times 8 \times 10k/_2 = 2.9k$, which is only about 1 per cent of the heat transferred in this case, where the air is 10 deg. fahr. colder than the hot plate.

The Code recommends that the standard mean temperature shall be 60 deg. fahr. and thus introduces a different basis of comparison from Part 3 of the Code, where 40 deg. fahr. is recommended. These should be made to agree.

Part 3 of the Code deals with over-all heat transmission, the guarded hot box method being specified, and it is presumed that this is the one described by Prof. F. B. Rowley in paper No. 748 of Vol. 32 of the Transactions. Unfortunately, the paper referred to does not give very full details of the box, as the illustrations are not clear, and if it is to be used as a standard a full description should be given. The writer, does not see, however, why the one method alone should be stipulated. In the University of Toronto, we have been using walls 4 ft. wide and 5 ft. high with an area of 20 sq. ft., the hot box being 18 in. deep inside and surrounded by 4 in. of cork board and $^7/_8$-in. wood sheeting. Instead of the outside box used by Professor Rowley, we simply use the air in the room, which we can keep quite nearly constant. These larger specimens are likely to give much more accurate results than the smaller ones, because, in an area of 20 sq. ft. the sample is much more representative than in the 9 sq. ft. used by Professor Rowley and the error due to heat losses would ordinarily be much less.

As a comparison of the accuracy of the two boxes, one wall tested at Toronto might be taken as an illustration, in which the amount of heat per hour passing through the wall was 500 B.t.u. The mean area of the test box walls is 55.5 sq. ft., and if the effect of the wood sheeting is neglected and a value of k equal to 0.36 is used for cork, the heat radiated from this box would be $55.5 \times 0.36/4 = 5$ B.t.u. per deg. fahr. difference in temperature between the inside and the outside of the hot box which amounts to a loss of only 1 per cent of the heat transferred.

In the Rowley box, which is a 3-ft. cube surrounded by 2-in. cork board, the corresponding heat transmission through the test wall would be 225 B.t.u. per hour. The mean area of the cork board in the inner test box is 50 sq. ft., hence the radiation loss would be $50 \times 0.36/2 = 9$ B.t.u. per hr. per deg. fahr. temperature difference. This error is 4 per cent, or four times as great as in the case of the larger wall. It is quite probable that the temperature of the outer box may vary 2 deg., which will produce the same proportional error as an 8-deg. fahr. variation in the air surrounding the Toronto box; and it is quite easy to keep below this variation in room temperature. This is not meant in any way to be a criticism of Professor Rowley's method but to show that its accuracy is no greater than other methods in use, and which should also be approved by the Code. It is important to have the area of the test wall as large as possible and the Code should be so made as to permit the use of larger walls or equally exact methods being employed in place of one named.

The suggestion of thinning down the edges of the inner box to make good contact with the specimen may not be very satisfactory; as a matter of fact, the current produced by the fan is likely to cause air to pass directly from the inner to the outer box or *vice versa*, unless perfectly tight contact is made, and this may result in a more serious error than is being guarded against. The last sentence of paragraph 4, page 255, says, that "fans shall be installed to maintain uniform temperature in all of these spaces with minimum circulation of air." It is well known that the coefficient of heat transfer is very sensitive to air currents over the specimen and the method of air circulation should, therefore, be described in exact detail, as any difference on this point will result in quite serious changes in the coefficients.

The second paragraph on page 255 evidently means that the temperature on the cold side of the specimen shall be zero, and on the hot side 80 deg. fahr., both of which temperatures are extreme for building walls, and it must be pointed out that it is almost impossible to secure the same temperature on two sides of the walls for different materials. Further, it is almost impossible to keep the temperature on either side absolutely constant during a given test. The writer would suggest that the Code permit of a temperature of from 0 to 20 deg. fahr. on the cold side and between 60 deg. fahr. and 80 deg. fahr. on the hot side, with a recommended temperature difference of perhaps 50 deg., if possible. In this same connection, attention is called to the 12th line on page 255 where it is stated that the mean temperature of the wall must not exceed 105 deg. fahr.; there seems to be no reason suggested in the Code for this high temperature and it must refer to walls being used for other purposes than ordinary buildings. It seems to be quite inconsistent with the statement in the paragraph above it, which gives a mean temperature of 40 deg. fahr., and with the paragraph in Part 2 which gives a mean temperature of 60 deg. fahr.

The second paragraph of Part 3 states that the duration of the tests shall be from 2 to 4 hrs., but this ought to be carefully qualified, because, it is too short unless several hours running previous to the test period show that the temperatures are constant, which is equivalent to stating that the test should last for a longer period than specified.

In the description of the construction of the guarded box it is recommended that the heating wire be wound on a cubical frame not to exceed 12 in. on a side, and this should be more clearly defined. The writer cannot see why this particular construction is suggested.

In Section 2, page 255, under Specimens for Tests the report says that, "The portion of the specimen through which the flow of heat is actually measured shall be at least 3 ft. x 3 ft.," whereas, in the construction of the guard box, it is stated that it must be 3 ft. x 3 ft.

The last paragraph on page 255, refers to the thermocouples, but is very indefinite. No information is given as to the positions of the thermocouples and the code should state where they are to be placed.

The writer hopes that the Code will receive very careful consideration before being adopted by the Society. If it is such that the laboratories can carry out the recommendations it will become of very great value and will be greatly welcomed by all those working in this particular field, but if the Code is made in-

definite and as restricted as it is in its present form, it cannot be adopted in a practical way by the different laboratories, and they are not likely to work with it at all.

R. H. HEILMAN: The adoption of this Code by the Society should help to improve the conditions now existing in the low temperature field; if for no other reason than that of convincing future investigators of the advisability of determining conductivity coefficients by a standard method and plotting of their resulting conductivity coefficients as a function of mean temperature, and not temperature difference.

There is one statement made in the Code which I think should be changed, namely, the statement that "the temperature of the surfaces of the materials shall be regarded as that of the plates on each side." Any one who has had actual experience in testing of heat insulations knows definitely that the temperature of the surfaces of the materials is rarely the same as the temperature of the plates, and that the conductivity values as calculated by the plate temperatures will usually give values of 5 to 10 per cent lower than the true conductivity of the materials tested, and especially when thin samples are used.

One can readily see that it would be difficult to check over-all tests on a thick wall from conductivity values obtained on various relatively thin samples by the plate temperature method.

One other item of less importance is the statement that "The construction of apparatus, and the procedure recommended by the United States Bureau of Standards, JOURNAL of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 26, No. 7, October, 1920, shall be followed."

This statement would eliminate other apparatus now in use which is, no doubt, equally or more accurate than the apparatus specified in the Code.

It is very doubtful as to whether accurate coefficients of over-all heat transfer can be obtained by the guarded hot box. If this apparatus is to be recommended in the Code, and a standard mean temperature adopted, should not this standard mean temperature be the same in both cases instead of 60 deg. fahr. for the hot plate and 40 deg. fahr. for the hot box?

It is highly desirable as recommended in the Code that coefficients of heat transmission be obtained for several mean temperatures of the wall, this should also be recommended for conductivity coefficients obtained on insulating materials by the hot plate method. The accuracy of the results in either case will be improved by a plurality of points at various mean temperatures with a line drawn through the average of the points.

PROF. G. L. LARSON: Until a few days before leaving Madison, I did not know that Prof. Kratz could not be here, but I received a letter from him appointing me as his attorney in presenting this Code. I shall not read the Code. I know that those who are interested in it have read it very thoroughly. In fact, according to the correspondence that Prof. Kratz turned over to me, some have read it so thoroughly they find a lot of things in it that are not there, and which were never intended to be there. Therefore, I am simply going to present the Code to this Society for approval or rejection and ask that the committee be discharged.

W. H. CARRIER: I have no personal criticism to make with reference to this Code. I think that the members are all very capable and they worked very hard on this and their purpose is to get it before the meeting to add the criticisms and suggestions of other members which, of course, the committee undoubtedly will take into account. There is one suggestion that I have to make. The AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS is not the only national society representing industries of great importance that are interested in a Code of this character. The refrigerating engineers use insulation and insulated apparatus construction to a far more important economic end in a great many cases than heating and ventilating engineers. With the refrigerating engineer, this is an absolutely vital thing. It is just as vital as the performance of his equipment. The industries represented by refrigeration, including the ice manufacturer and household machines, all of which are vitally interested in insulation and proper methods of testing insulation requirements, represent in the neighborhood of a billion dollars a year business. The *American Society of Refrigerating Engineers* is not such a large society but they do represent the most forward of these interests.

The *American Society of Mechanical Engineers* through their power department has also a very vital interest in a proper code of this character. I am sure all these societies will greatly welcome the constructive efforts of this Society and the initiative this Society has taken to produce a practical code for measurement which has never been satisfactorily settled and in which such chaotic conditions admittedly exist.

There has been a purpose of two or three organizations to tie together the interests of the various societies in various lines of endeavor to a common effort. We have had our Boiler Code Committee that you know was fostered by the *American Society of Mechanical Engineers*. The AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS cooperated with them. The boiler manufacturers cooperated. As a result we have a Code which we believe is as near satisfactory as possible and which we are all agreed is very desirable.

The same thing, in view of these outside interests, I believe, should be done with this. The machinery for this may lie in two distinct organizations. The first is the American Engineering Standards Committee who have fostered, for example, the standardization of the safety Code in refrigeration. It is true they arranged a representation from the *American Society of Refrigerating Engineers* and the *American Society of Mechanical Engineers*, and, I think, possibly civil engineers in that case. This Code has been made satisfactory to every one and I think is ready for final adoption.

The other society which, I believe, is most fitted to handle this and handle it so as to correlate the interests of all parties, your interest, the interest of the refrigerating engineers, which is equally vital if not more so, the *American Society of Mechanical Engineers*, of which there are various branches that are interested apart from heating and ventilating is the Heat Transfer Committee under the auspices of the National Research Council. This Society has representation on that Council. In fact, I am chairman of that committee at present. We have just raised a fund of $12,000 annually for three years, so that we can get into active operation. We now employ a paid technical executive to see that this work goes on in a

constructive way. We have an office and equipment. It is all very recent so it is all news to you.

The intention is that we shall primarily cooperate with all the organizations that exist that are interested in this phase of the subject; not only the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS but the *American Society of Refrigerating Engineers* and the *American Society of Mechanical Engineers* all have representation, either have or will have, on this committee.

In a case of this kind it would be necessary to appoint a committee representing various interests and I would like to see that carried out through the Heat Transfer Committee of the National Research Council. I believe that is the logical place. The idea of that committee is to correlate all these efforts and I am sure in your work it is one of the objects to get such assistance and help on the part of others and to correlate the work so that whatever is accepted here will be a universal standard for all the societies that are interested in the whole United States. I know that you will appreciate that it will be a great honor and a great privilege of this Society to propose a Code with perhaps some of the changes that have been offered here today consideration for such a body so that when this consideration is given and the sign of approval given by the various organizations interested through such a committee, you will have something that will be nation-wide for all industries and then we may eventually have it world-wide.

I believe it will be a great achievement of the AMERICAN SOCEITY OF HEATING AND VENTILATING ENGINEERS to cooperate that way. My suggestion is that you not adopt this code as it is here today or even as it is amended until it has been received and accepted as it undoubtedly will be with very slight suggestion and change through some such national organization correlating all the efforts of the various societies.

I would like to make a motion to that effect that action be postponed until accepted as standard by the other societies. I assure you with the present machinery we have we will push this right through. I would also like to suggest in my motion that at least two members of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, probably the Director of Research and one or two others, be delegated to act on that committee which will be formed through the Research Council, and represent this Society, the Refrigerating Engineers and the *American Society of Mechanical Engineers*. Let us make this thing universal and general.

W. S. TIMMIS: I take pleasure in seconding the motion. I would like to add with the consent of the proposer that the *American Institute of Architects* might be interested in this subject, because when the matter of insulation has been thoroughly brought to the attention of the architects they can take advantage of that in designing their buildings, and if Mr. Carrier has no objection I would like to have a committee from the *American Institute of Architects* represented on that matter.

MR. CARRIER: I am perfectly agreeable to that.

PROF. ANGUS: Before that motion is put, might I say something? If you refer that to a committee in which the National Research Council of the United

States alone is represented, we on the other side of the line will be left out. We Canadians are supposed to have a colder country than the United States, and that is generally true, so that we are greatly interested in this matter of heat insulation. I ask that you include in the motion a representative of the National Research Council of Canada.

MR. CARRIER: I will accept that amendment.

PROF. F. B. ROWLEY: The Code, as now presented, is very nearly the same as the one tentatively adopted by the Society last spring. At that time some of these same objections came up, but as far as I know, none of them have since been presented to the Code Committee which was retained for the purpose of making any revisions necessary and getting a workable Code. There is no question but what there has been a great difference in the results obtained by tests on the same material, due to different methods or different interpretation of the results. Twenty per cent or more is not uncommon. For instance, a wide variation may be accounted for by the mean temperature used. As I understand it, the reason 60 deg. was taken by the Committee was in order to get down nearer to the temperatures at which these materials are to be used.

PRESIDENT ANDERSON: I desire to raise a point of procedure. Are you speaking to this motion of Mr. Carrier's?

PROF. ROWLEY: I was discussing the Code in general.

PRESIDENT ANDERSON: While we were discussing the Code I accepted the motion. I may have been in error in that, but as long as that motion has been accepted, I will have to deal with it now.

MR. CARRIER: I will withdraw my motion and make it at the end of the discussion.

PROF. ROWLEY: Sixty degrees is a temperature which can be used in the laboratory by proper precautions against condensation. Some of the points which have been brought up against the Code are more or less criticisms of the details of construction and probably need not be discussed.

Professor Angus brought up the point that the size of the specimen was only 3 ft. square. As a matter of fact the specimens are 5 ft. square, the outer portion which is the most inaccurate, on account of end losses, is eliminated from the final results. These results will naturally be more accurate than would be the case if we took the average for the full wall section.

The question of the Society adopting or not adopting this Code is one of the necessities of getting down to some standard method whereby results can be obtained and reported with a reasonable degree of accuracy and uniformity. This Code was accepted tentatively last spring with the idea of using it until some better form could be prepared. If we throw it over now, there is no telling when we will get further action. It will leave all of the insulating material men and all of the laboratories that are doing this work without any standards to go by.

It seems to me that the proper thing to do, regardless of these details which can be ironed out later, is to adopt the Code as a tentative working Code. Any Code, as an example of boiler Code for the *American Society of Mechanical Engineers*,

must be a living thing. It must be something that can be changed as we find better methods of testing and extend our knowledge of the subject. We must keep it up to date but we are not going to get very far if we shelf it or lay it on the table and leave it for some future generation to tackle.

My suggestion is that it be adopted as it is at least as a tentative code. I do not think that anybody wants to adopt a code that is not fair to all concerned. It is a matter of getting something that we can work by. We have been at this for a long time and to side track it now may mean another long delay.

PROF. LARSON: May I speak a few words in behalf of the committee? Suggestions have been made here that the size of the box be not definitely stated and also that the mean temperature be variable depending upon the conditions under which other laboratories work. That is more or less what we tried to get away from, and is the difficulty that the insulating manufacturers have at the present time. The reason this committee was born was to bring out some more standardized method so that these manufacturers could advertise their product based upon tests made under standard conditions. The trouble is now, as I see it, that the advertising matter that is coming out on insulation is based on so many variable types of tests, different sizes of boxes, different constants, different temperatures of test, that they felt the need of something definite in order that the results might be a little more relative.

PROF. ANGUS stated that the size of the box should not be definite and then in the next sentence he stated that the location of a fan and the thermocouple should be very definitely stated. I don't see how you can be consistent in that kind of an arrangement.

PRESIDENT ANDERSON: Prof. Rowley referred to the Boiler Code of the *A.S.M.E.* which was started before we were born and it was only a few years ago that they finally put it in definite shape. So that we haven't been so slow in the development of this Code after all when you consider how other societies have taken plenty of time in the formation of engineering codes.

J. H. BRACKEN: Prof. Rowley anticipated much of what I was going to say. If you will pardon me for stating what I think is this Society's interest in this Code, it is this, to get the accurate statement of the heat coefficients of individual materials so that by the use of a formula we can determine the overall heat transmission through this wall or that wall or any other wall. The determination of those unit coefficients is best achieved (and I have heard nothing stated in criticism against this claim) by means of the hot-plate test. In fact, all the criticism deals with refinements only of this test.

No man has stated that these methods are incorrect or should not be adopted. Toward the hot-plate test only two criticisms have been made. One is the mean temperature of 60 deg. fahr., and the difficulty of maintaining a low temperature on the cold side of the plate in summer because of the dew point (the condensing of moisture and that sort of thing, and the other is testing the materials dry).

Well, now the criticism we have had of the coefficients published by various persons and technical schools is that the same material, this piece of paper, for example, is tested in Toronto and in New York and San Francisco and New Orleans

and different results are published. The results should certainly be the same for this individual piece of paper, but they are not. If you take this piece of paper and everywhere follow the methods that are laid down in this test, you certainly ought to get a comparable result. To say that we shouldn't test the material bone dry is to say that we shall leave in each sample an undetermined factor, an amount of moisture which nobody is to determine, which may be 15 per cent in New Orleans and may be 2 per cent in Toronto. I don't see any use in that. If it is true that these materials afterward accumulate moisture, then we will have to have another determination entirely separate from this sort of thing in order to add another factor for the walls, for the moisture content, but that is no criticism to bring up against this Code whatever.

I should like to see the Code adopted. I am very much in favor of having it brought to the attention of the other societies as Mr. Carrier suggests. We have been thinking about this Code and looking over it for a very long time and it seems to me this is the best thing that has yet been produced.

PRESIDENT ANDERSON: Any other comments? I must confess I am not able to sense the views of the meeting. It seems to me there have been so many ideas interjected into this discussion. I do not want to be in the position of forcing the adoption of the Code, nor do I want to be in the position of passing it over and continuing unnecessarily further consideration.

A. A. ADLER: The present Code as it stands now is a job that is done. Why not adopt it? If you want to be cautious, call it a tentative Code, but adopt it now. It is no reflection on the ability of other organizations because they have not been invited in writing this Code. I have seen the start and finish of many codes, including the Boiler Code. The latter was out of date when it was adopted and because it must follow the developments of the art, is continually out of date. Just as soon as the pressure gets great enough, a revision brings it up to date and by the time it is adopted, it is again out of date. This committee will have to continue to function as long as the Society exists. In justice to the men who have given so much time to write it I think it a matter of courtesy for us to accept the Code as a Code. Mr. Carrier's suggestion requesting other organizations to assist in revising it may be considered as the start of a new job. I will make that as a motion, Mr. President.

PRESIDENT ANDERSON: Make what a motion?

DR. ADLER: That we adopt the Code tentatively and invite the other societies to assist in its revision.

PROF. LARSON: I will second the motion.

H. M. HART: I wanted to say that I second the motion not from a standpoint of courtesy. I never knew this Society to feel courteous toward anybody. But as near as I can see if materials are tested by this Code we will have a fairly true measuring stick for determining coefficients of transmission and that is what we are seeking. For that reason alone I second the motion and I hope it will carry. I will also be glad to vote in favor of Mr. Carrier's motion.

S. R. LEWIS: I can answer for the Committee on Research that this committee

will be kept alive and that the suggestions which have been offered here will be incorporated.

I am glad to say that there are already in our possession a large number of tests that have been made at the University of Minnesota tending to improve or change this tentative Code.

D. K. BOYD: Speaking as an architect, I am very glad that the subject was brought up of having the American Institute of Architects included in the organizations to which this Code would be referred. Speaking to the motion to have this Code tentatively adopted I want to say that there is to be a meeting tonight of the manufacturers of insulating materials at which I will be present as consulting architect to the MacAndrews & Forbes Co. That meeting hopes to be able to definitely refer to this Code which will thus give all of the manufacturers a yardstick, as was so well pointed out, by which they can measure the efficiency of their products at this time and the results of which can be expressed in comparable terms.

MR. CARRIER: I would like to make a motion that this Code be referred to the Committee on Heat Transfer of the National Research Council for its consideration, inviting in other societies and interests who are interested in the Code, namely, the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, the *American Society of Refrigerating Engineers*, the *American Institute of Architects*, the *American Society for Testing Materials*, the *American Society of Mechanical Engineers* and the *Canadian Research Council*.

MR. BOYD: You misconstrued my remarks before. I was speaking in support of the adoption of this as a tentative standard, because it can then be definitely referred to at a meeting which is to be held tonight, but, speaking to your present motion, it would seem to me that to close the doors by specifically naming five different organizations to the exclusion of perhaps some one or two others which might be later interested, would be unwise.

MR. CARRIER: And others that may signify their interest.

MR. BOYD: If that motion could be amended to say "others who may be interested" I would so amend.

MR. BRACKEN: Do you think it would clear up the matter if we had some statement from Mr. Carrier as to what will happen after it is referred to these societies?

MR. CARRIER: The plan is to have this Society refer this to the National Research Council, and through its Heat Transmission Committee, secure universal acceptance of this Code by all the Societies interested.

PRESIDENT ANDERSON: The motion then is this: that this matter be referred to the National Research Council through its technical committee known as the Heat Transfer Committee, with the distinct purpose of getting the cooperation of various interested Societies and others to prepare the Code in some permanent shape that will be acceptable to all interests.

The motion was carried.

H. M. HART: That carries with it that our present committee is to be continued.

MR. CARRIER: Oh, yes. And the report submitted back to this Society and its committee for any further adoption or rejection as they see fit. Of course, this Society will have its very ample representation on this committee. What actually will occur, to answer this question—immediately on receiving it we will ask these various societies, including your own, to appoint representatives on such special committee and the meeting will be held at the earliest possible date, probably within one month and as fast as they can come to any fair agreement on this matter in sections, we will adopt the Code.

PRESIDENT ANDERSON: Mr. Hart, I would be glad to have your motion as a separate motion.

MR. HART: I move that the present committee be continued.

MR. LEWIS: I don't see why it is felt necessary to usurp the privilege of the chairman of the Committee on Research. I promised you that we would see that the committee was continued. If Mr. Kratz declines, we will put some one else on. Why must we compel him to accept if he doesn't wish to?

PRESIDENT ANDERSON: I take it that the spirit of the motion is that we continue this committee.

The motion was carried.

MR. BOYD: In acquainting the other organizations with the Code I assume that they will also be furnished with printed copies of the discussions which have taken place here today such as those about the size of the plates and specimens and all others that may be sent in writing.

No. 800

VALUE OF BUILDING INSULATION TO REDUCE HEAT LOSSES

By E. N. SANBERN,[1] PHILADELPHIA, PA.

MEMBER

THERE is hardly a man present who has not at some time in his life come across a paragraph in a specification in which the following words occurred, although they may differ slightly in arrangement. "The contractor shall guarantee to heat the building to 70 deg. in zero weather."

No self-respecting engineer would today issue a specification with this clause. That it is meaningless from an engineering point of view is quite obvious to any one who understands heating and ventilating. There was, however, a time when the use of this clause very closely approached 100 per cent of the specifications issued.

In the days before the Society had been formed, and in the days of its infancy, the common rule for figuring the heat loss was first, cubic contents, afterward the Mills rule and then the Carpenter rule. But today, heat loss can be determined with reasonable accuracy, if the type of construction is known and the workmanship is good. In the future, instead of the heating contractor being held responsible for the heating of the building, the heating contractor will be in a position to demand that the building contractor so construct his building that the heat loss be that which the engineer figures it should be.

THE GUIDE, 1928, has a number of tables that are very accurate as to the B.t.u. loss through various types of building construction, insulation and other materials, and has a number of pages showing the amount of losses for various combinations of structures.

The heat loss coefficients that are given in the 1928 issue of THE GUIDE are from such eminent authorities as U. S. Bureau of Standards; Willard, Lichty and Harding; Peebles, Norton and others.

Mr. P. Nicholls, formerly of the Society's Research Laboratory at Pittsburgh, developed a meter that can be installed in any room and the actual heat loss through an existing wall or other structure can be determined to a degree of accuracy that would have been deemed impossible a few years ago. It will, therefore, readily be seen that if the engineer can determine by calculation what the heat loss should be and after the construction, check these conditions, he will stand on firm scientific,

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Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

as well as practical ground, and then demand that the building be constructed to limit the escape of heat.

The heating engineer is not only being faced with the problem of properly heating the building, but also of insulating it. This problem of insulation is one that cannot be solved by the architect or building contractor. The mere application of insulating material to a building will not give the owner of the building the answer to his problem; for, as can readily be seen, should the cost of insulating material be such that it would be cheaper to burn coal than insulate the building, it would be a waste of money to insulate.

Insulation from a commercial standpoint is not a problem of saving coal, but of saving dollars in the first and operating cost, and although coal costs money, there is a distinction as well as a difference. It is the purpose of this paper to try to show how the problem of insulation of a building should be approached that the owner may receive the greatest possible benefit per dollar of expenditure.

Before going into the problem of insulation, some of the terms used in the B.t.u. method of calculation will be defined.

Heat losses from building occur through the building construction by radiation, conduction and convection. Heat always passes from a higher to a lower temperature. If the temperatures are the same on both sides of the wall, there will be no transfer of heat. Therefore, the greater the temperature difference, the greater the rate of heat transfer. Take for example, a room with 13-in. brick wall furred and plastered, one wall exposed and heated with a direct cast-iron steam radiator. The steam in the radiator being of a higher temperature and in contact with the cast iron, the heat passes through the cast iron by conduction, and is given off on the outside of the radiator by radiation and convection.

Radiation passes from the radiator in straight lines, through the air without appreciably heating it, to the walls and other objects in the room, giving up its heat to them. The air in contact with the radiator absorbs heat and by its difference in temperature will circulate through the room, giving up its heat to the cooler wall and objects. This is called convection.

The heat has now been traced to the walls. There being only one exposed wall, this is the only one in which any transfer of heat will take place. The inside plaster wall has received its heat by radiation and convection, and will transfer the heat by conduction through the plaster to the furred space where it will again pass through the air in the furred space by radiation and convection to the inside surface of the brick wall, and then through the brick wall by conduction, and be given off on the outside of the brick wall by radiation and convection. There is a drop in temperature through each of the various steps just described.

The combined coefficient of radiation and convection in the examples to follow will be called K, and the coefficient of conduction will be called C. The infiltration of air around the doors and windows must also be considered and just a brief description of how the coefficients for the various materials are obtained will be given.

There are two methods used at present, one is called the hot box, and the other the hot plate. With the hot-box method, there are two boxes; one smaller than the other. The smaller one contains the heating elements and is built inside of the larger one. Both boxes have one open end in the same plane and open into

a room that is cooled by a refrigerating system. The material to be tested is placed over the open ends of the boxes. After the temperatures are adjusted, so that the rate of heat flow is constant, the engineer can by the use of instruments and thermocouples get the coefficients desired. In the hot-plate method, there is a heating element either an electrical or steam hot plate with the material to be tested placed on each side of the plate and a cooling section again placed on the outside of the two test sections. These sections are all clamped together. By measuring the temperatures in the hot plate and in the cooling plate, the rate of heat transfer is obtained. There is one thing that should be done that is not being done now, and that is to test the material at the temperatures they are going to be used.

It is known today that by insulating a wall or roof with some kind of insulating material, quite a saving in heat loss is possible. Every one knows that cork is a good insulating material, but rather expensive. There are on the market today, insulating materials that equal or very closely approach the insulating qualities of cork and they are cheaper, and in many cases more easily applied. Insulation may be classified under five different headings as follows:

1. The loose or dry, powdery type.
2. The poured or gypsum base, where the material is mixed with water and poured into place with forms.
3. The quilted, where the material is stitched between two layers of paper or some similar material.
4. The felted, where the material is in a semi-pliable condition and very similar to a heavy felt.
5. The board or semi-rigid type, which is often used in place of lumber.

The various types of insulators having been defined, now consider some of the places they might be used. It is very essential to pick the proper insulator for a specific job. All insulating materials have their use, but any one particular kind will not answer for every purpose.

There is one important thing to remember, and that is, there are no insulators known that will not absorb moisture if brought in contact with it, and some insulators will absorb more than others. Then, if a room or factory in which the process of manufacture either requires or results in a high humidity, the insulator should be protected by some water-proof material. The walls and ceiling construction are naturally cooler than the air in the room, and will cool the air. If the air is cooled down to the dew point, water will be deposited on the surface of the insulator. When the insulator absorbs moisture, its insulating value is practically destroyed.

Vermin is another thing to be considered in using an insulator. If the product being manufactured in the building will attract vermin, then an insulator should be used that will not harbor them, and one that is difficult for them to destroy.

Fire hazard is another question to be considered. If the risk is great, it is better to use an insulator that is fire retarding. Some of the insulators on the market today are either fire retarding or slow burning.

For a practical problem consider a small factory of modern construction. The walls are usually of brick or concrete without any furring or plaster on the inside.

This makes it almost impossible to do anything in the way of insulating without considerable extra expense. It is hard to justify insulation on the walls of a modern factory as the exposed glass area will run anywhere from 50 to 75 per cent of the total exposed wall area. This does not leave much wall surface to be insulated. One square foot of glass in this type of construction is equal in heat loss to about 4 sq. ft. of 13-in. plain brick wall which shows that the window is the greatest source of heat loss. The window problem is a big one and until heavier and better windows that will not leak or warp are made, the engineer is helpless. There is one place in the factory that insulation can and should be used, and that is on the roof. As there is a higher temperature at the ceiling, naturally there is a greater heat loss at this point which justifies the use of insulation.

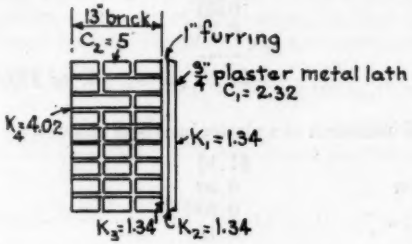
In the home, the wall construction is such that it is easier to install insulation as the glass area will vary from 15 to 25 per cent of the total wall depending on the design. This gives a larger percentage of wall surface to insulate. The home is a place for comfort and engineers are justified in spending a little more here than on the factory wall. Insulation not only saves fuel, but tends to give a more uniform temperature throughout the house and helps to stop infiltration through the wall. In tests made at the A.S.H.&V.E. Research Laboratory, it is shown that a 13-in. plain brick wall under pressure of a 15-mile wind will leak about $7^1/_2$ cu. ft. of air per hour per square foot of wall surface. This same 13-in. brick wall with furring and plaster will leak about 0.21 cu. ft. of air per hour per square foot of wall, and by using insulation, this leakage should be still further reduced. This alone means quite a saving.

In schools the walls are often of such construction that insulation can be easily applied. Here the glass area will run about 45 to 55 per cent of the total wall. Insulation cannot be justified if it is necessary to go to too much extra expense. That statement applies to the climate of Philadelphia and the use of cheap fuel. If the cost of fuel is high, and the temperature difference is great, it is very much easier to justify the use of an insulator as will be seen later in this paper.

Where should the insulator be placed in the wall? The best way to install the insulation from the standpoint of efficiency of heat transmission is to place it in the center of an air space, so that it will divide the air space into two smaller air spaces. This gives what is commonly called two dead air spaces. Still air is a very good insulator, but due to methods of building construction it is almost impossible to get still air. When heat is applied to one side of the wall, it is transmitted through the material by radiation and conduction and the air next to the warm wall becomes heated and starts to circulate giving up its heat to the cold wall by convection. Just what the correct width an air space should be is not known, but it is thought that about 1 in. is correct for most materials. The materials facing the air space would have some effect on the width. If strips could be placed in the air space, dividing the wall into several smaller spaces, it would tend to cut down the convection currents. The Laboratory at Pittsburgh has been running some tests with the heat meter in some of the homes of the Westinghouse employees. These homes are heated by electricity, so that will give a very good check on the present figures.

A few examples to see if insulation can be made to pay will be given. Assume that the building has 13-in. brick walls with furring, metal lath and $^3/_4$-in. of plaster.

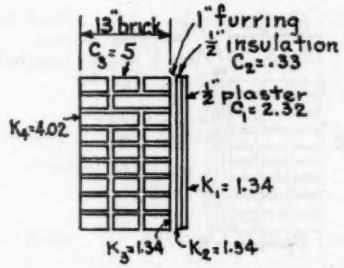
The first thing to figure will be the heat loss constants using the coefficients K and C that were obtained by tests on the materials in question. (Fig. 1.)



$$U = \frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{X_1}{C_1}+\frac{X_2}{C_2}} = \frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.75}{2.32}+\frac{13}{5}} = \frac{1}{5.41} = .185$$

FIG. 1. CALCULATION SHEET FOR UNINSULATED WALL

Now take a 13-in. brick wall, furring with $^1/_2$-in. of insulation used as a plaster base and a $^1/_2$-in. plaster. (Fig. 2.)



$$U = \frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{X_1}{C_1}+\frac{X_2}{C_2}+\frac{X_3}{C_3}} = \frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.5}{2.32}+\frac{.5}{.33}+\frac{13}{5}} = \frac{1}{6.818} = .147$$

FIG. 2. CALCULATION OF HEAT LOSS FOR WALL WITH $^1/_2$ IN. OF INSULATION

Then take a 13-in. brick wall with 1 in. of insulation used as a plaster base and $^1/_2$ in. of plaster. (Fig. 3.)

Now that the heat constants have been obtained, the cost of construction of the various walls must be investigated. The cost of the brick wall will be the same in all cases, and the only cost that must be considered is the difference in the cost of the metal lath and plaster, and the insulation as a plaster base with plaster.

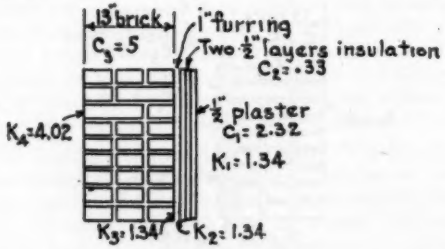
The cost of the metal lath construction is as follows:

Plaster	$1.35
Metal lath	0.20
Labor	0.20
	$1.75 per sq. yd. or $19.44 per 100 sq. ft.

The cost of 1/2 in. of insulation as a plaster base is as follows:

Plaster	$1.15
1/2-in. insulation	0.50
Labor	0.10
Wire	0.15
	$1.90 per sq. yd. or $21.11 per 100 sq. ft.

The wire referred to in the example is the ordinary galvanized chicken wire with about a 1-in. mesh. This is stretched tight over and nailed to the plaster base insulation. This is done to prevent large cracks in the plaster at the joints in the insulation. If the wire is not used and if there is any vibration, shrinking or settling of the building material, the plaster will crack at the joints. The wire acts as a reinforcing for the plaster and divides the cracks up so that they appear only as very fine hair cracks.



$$U = \frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{x_1}{C_1}+\frac{x_2}{C_2}+\frac{x_3}{C_3}} = \frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.5}{2.32}+\frac{1}{.33}+\frac{13}{5}} = \frac{1}{8.333} = .120$$

FIG. 3. CALCULATION OF HEAT LOSS OF WALL WITH 1 IN. OF INSULATION

Doubling the thickness of insulation, the cost is as follows:

Plaster	$1.15
2 layers insulation	1.00
Labor	0.20
Wire	0.15
	$2.50 per sq. yd. or $27.77 per 100 sq. ft.

The cost of fuel will be taken on the basis of $2^1/_4$ tons of coal per 100 sq. ft. of steam radiation per heating season of 210 days or 0.0225 tons for 1 sq. ft. per yr. As a basis take No. 1 buckwheat coal at $7.50 a ton. Then 0.0225 x 7.50 = $0.169 per sq. ft. per heating season. The cost of radiation will be $2.00 per sq. ft. in place. The amount of radiation for the different types of wall considered are as follows:

Metal lath $\frac{0.185 \times 70 \times 100}{240}$ = 5.4 sq. ft. rad. per 100 sq. ft. wall.

$^1/_2$-in. insulation $\frac{0.147 \times 70 \times 100}{240}$ = 4.3 sq. ft. rad. per 100 sq. ft. wall.

Two layers insulation $\frac{0.120 \times 70 \times 100}{240}$ = 3.5 sq. ft. rad. per 100 sq. ft. wall.

Now figure the cost per year per 100 sq. ft. of wall, considering the cost of fuel, interest at 6 per cent on additional building investment and depreciation on the heating system over a 20-year period. This will give a comparison of the cost of 100 sq. ft. of wall.

The figures used here on the costs of plastering were obtained from a reputable firm of plasterers in Philadelphia.

13-in. brick wall with metal lath:

Plaster, metal lath	$19.44	
5.4 sq. ft. radiation at $2.00	10.80	$0.54 Depreciation
Coal per year, 5.4 sq. ft. at $0.169		0.91 Fuel cost
	$30.24	$1.45 Annual operating cost

13-in. brick wall with one layer of $^1/_2$-in. insulation:

Plaster, one $^1/_2$-in. layer insulation and wire	$21.11	$0.10 Interest additional building investment
4.3 sq. ft. radiation at $2.00	8.60	0.43 Depreciation
Coal per year, 4.3 sq. ft. at $0.169		0.73 Fuel cost
	$29.71	$1.26 Annual operating cost

13-in. brick wall with two layers of $^1/_2$-in. insulation:

Plaster, two $^1/_2$-in. layers insulation and wire	$27.77	$0.50 Interest
3.5 sq. ft. radiation at $2.00	7.00	0.35 Depreciation
Coal per year, 3.5 sq. ft. at $0.169		0.59 Fuel cost
	$34.77	$1.44 Annual operating cost

In the example given the wall with $^1/_2$-in. layer of insulation at a cost of $1.26 per 100 sq. ft. of wall will give the cheapest installation.

Nothing has been added in the figures for taxes as they would be constant. The tax assessor seldom knows how the wall is constructed. His figure is usually based on the size, location and type of building.

Depreciation on the additional building investment has not been figured in for the following reasons: The U. S. Income Tax return does not allow a person to figure depreciation on his home, but does allow 2 per cent on factories and other buildings.

It is very seldom that a building lives its full useful life, due to obsolescence. A building may become obsolete for the purpose for which it was built, and be torn down and replaced by a different type of building at a time when the walls were as good as when built. It would be hard to say what figure to use for obsolescence. Should any one care to add these factors, they should be added in with the interest on the additional building investment.

In the example, should the calculations have been figured the use of a fuel costing $15.00 per ton the annual operating costs would then be:

13-in. brick wall with metal lath:

$0.54 Depreciation
1.82 Fuel cost

$2.36 Annual operating cost

13-in. brick wall with one layer of 1/2-in. insulation:

$0.10 Interest additional building investment
0.43 Depreciation
1.46 Fuel cost

$1.99 Annual operating cost

13-in. brick wall with two layers of 1/2-in. insulation:

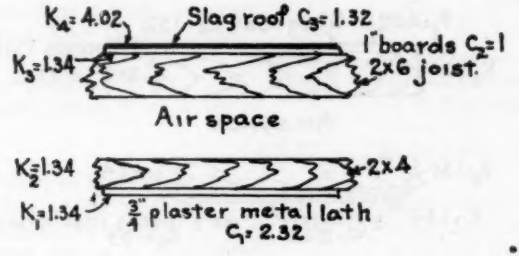
$0.50 Interest
0.35 Depreciation
1.18 Fuel cost

$2.03 Annual operating cost

In the example cited, using $15.00 per ton fuel, the wall with only 1/2-in. layer of insulation will give the cheapest installation.

There is one thing that the author wants to make clear, and that is that this is only a *method* of figuring. Every case should be figured and proved out. The figures used here are not correct for every location and type of construction, but may be varied to suit local conditions and types of construction. Any or all figures may be changed such as cost of radiation, cost of fuel, depreciation on heating system, rate of interest on additional building investment or the cost of building construction.

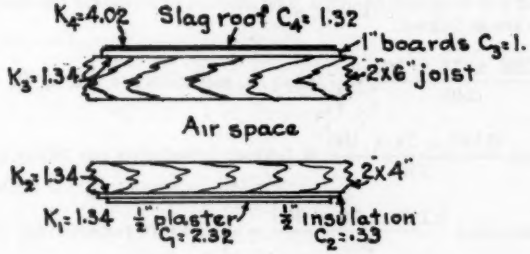
The ceiling will also show something that will be of interest. Take, for example, a roof of the following construction, one that is common in the Philadelphia home. Tar paper, slag, 1-in. roof boards, 2 x 6 joist with the lath and plaster ceiling suspended on 2 x 4 in. The air space will vary from 12 to 24 in. The heat loss on such a roof is as follows:



$$U=\frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{X_1}{C_1}+\frac{X_2}{C_2}+\frac{X_3}{C_3}}=\frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.75}{2.32}+\frac{.875}{1}+\frac{.25}{1.32}}=\frac{1}{3.875}=.258$$

FIG. 4. CALCULATION OF HEAT LOSS THROUGH ROOF

The same roof with 1/2-in. layer of insulation as a plaster base will give a heat loss constant as shown in Fig. 5.

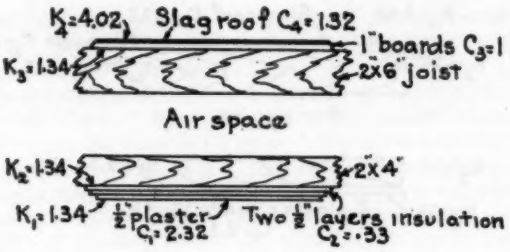


$$U=\frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{X_1}{C_1}+\frac{X_2}{C_2}+\frac{X_3}{C_3}+\frac{X_4}{C_4}}=\frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.5}{2.32}+\frac{.875}{1}+\frac{.5}{.33}+\frac{.25}{1.32}}=\frac{1}{5.283}=.189$$

FIG. 5. CALCULATION OF HEAT LOSS THROUGH INSULATED ROOF

Now the same roof with two 1/2-in. layers of insulation and plaster will be figured. The heat loss constant will then be as indicated in Fig. 6.

The cost of the various ceiling constructions will be the same, for the only thing that is being changed is the plaster and plaster base. Now the amount of radiation that each ceiling requires can be determined. Here the temperature difference will be greater, as the temperature increases about 1 deg. per foot of height and with an 8 ft.-6 in. ceiling and a temperature of 70 deg. at the 5-ft. line, the tempera-



$$U = \frac{1}{\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}+\frac{1}{K_4}+\frac{X_1}{C_1}+\frac{X_2}{C_2}+\frac{X_3}{C_3}+\frac{X_4}{C_4}} = \frac{1}{\frac{3}{1.34}+\frac{1}{4.02}+\frac{.5}{2.32}+\frac{.875}{1}+\frac{1}{.33}+\frac{.25}{1.32}} = \frac{1}{6.798} = .147$$

FIG. 6. CALCULATION OF HEAT LOSS THROUGH ROOF INSULATED WITH TWO ½-IN. LAYERS OF INSULATION

ture at the ceiling will be about 74 deg. The amount of radiation for the different types of ceilings are as follows:

Metal lath $\frac{0.258 \times 74 \times 100}{240}$ = 7.96 sq. ft. radiation per 100 sq. ft. ceiling

½-in. insulation $\frac{0.189 \times 74 \times 100}{240}$ = 5.83 sq. ft. radiation per 100 sq. ft. ceiling

Two layers insulation $\frac{0.147 \times 74 \times 100}{240}$ = 4.53 sq. ft. radiation per 100 sq. ft. ceiling.

Now figure the cost per year per 100 sq. ft. of ceiling, considering the cost of fuel, interest at 6 per cent on additional building investment and depreciation on the heating system over a 20-year period. This will give a comparison of the cost of 100 sq. ft. of ceiling. The price of coal and the cost of radiation in place and the cost of plastering will be figured the same as in the previous examples for walls.

Ceiling with metal lath:

Plaster metal lath	$19.44	
7.96 sq. ft. radiation at $2.00	15.92	$0.80 Depreciation
Coal per year, 7.96 sq. ft. at $0.169		1.35 Fuel cost
	$35.36	$2.15 Annual operating cost

Ceiling with one layer of $^1/_2$-in. insulation:

Plaster, $^1/_2$-in. layer insulation and wire	$21.11	$0.10 Interest
5.83 sq. ft. radiation at $2.00	11.66	0.59 Depreciation
Coal per year, 5.83 sq. ft. at $0.169		0.99 Fuel cost
	$32.77	$1.68 Annual operating cost

Ceiling with two $^1/_2$-in. layers of insulation:

Plaster, 2 layers $^1/_2$-in. insulation	$27.77	$0.50 Interest
4.53 sq. ft. radiation at $2.00	9.06	0.45 Depreciation
Coal per year, 4.53 sq. ft. at $0.169		0.77 Fuel cost
	$36.83	$1.72 Annual operating cost

In the foregoing examples for ceilings, the one with the one $^1/_2$-in. layer of insulation and a cost of $1.68 per 100 sq. ft. of ceiling will give the cheapest installation.

In the case of the ceiling, using fuel at $15.00 per ton, the annual operating costs would be:

Ceiling with metal lath:

$0.80 Depreciation
2.70 Fuel cost

$3.50 Annual operating cost

Ceiling with one layer of $^1/_2$-in. insulation:

$0.10 Interest
0.59 Depreciation
1.98 Fuel cost

$2.67 Annual operating cost

Ceiling with two $^1/_2$-in. layers of insulation:

0.50 Interest
0.45 Depreciation
1.54 Fuel cost

$2.49 Annual operating cost

In the examples for ceiling, using fuel at $15 per ton, the one with two $^1/_2$-in. layers of insulation will give the cheapest installation.

This is a very fair way to make the comparison, as the saving in the cost of fuel, saving in cost of radiation, saving in depreciation on radiation and the interest on the additional building investment have all been taken into consideration.

Insulation will also help to keep a house cooler in the summer by reducing the radiant heat from the sun through the wall and roof. There has been no attempt made to figure or show what this value would be in this paper.

Some engineers, no doubt, will not agree with me on the figures used in the problems, but they have been taken from THE GUIDE, 1928, which is very complete, and has a lot of new heat transmission factors and tables, so it will not be necessary to

figure them out as we have done in this case. THE GUIDE is rapidly becoming the leading textbook in the heating and ventilating field, and I hope the time will soon come when every one will use it as a standard, so all of us will be working on the same basis.

DISCUSSION

R. H. HEILMAN: I have not had a chance to read this paper thoroughly, but there is one item I have noted which is worthy of discussion. This is the matter of surface resistance. At the top of page 273, Mr. Sanbern calculates the heat transmission through a 13-in. brick wall with furring, metal lath and $^3/_4$-in. plaster.

He uses a value of 1.34 for K_1, K_2, and K_3 or for the first three surfaces. This value is not correct for K_3 and probably not correct for K_1.

If we assume 1.34 for K_2 as correct, then the value for K_3 should be considerably lower than 1.34 since K is the combined coefficient of radiation and convection. The radiation from one surface to another depends upon the difference of the fourth powers of the absolute temperatures of the two surfaces and, therefore, for the radiation alone the factor for surface (2) is tied up with surface (3) and cannot be separated. Since the radiation is at least 50 per cent of the total heat loss, it leaves only 50 per cent for the convection loss from surface (3) and K_3 should be only 0.67 instead of 1.34. It is very probable that the value will be even lower than 0.67.

Mr. Sanbern has no doubt obtained his values from the A.S.H.&V.E. GUIDE, where it is stated in Chapter I, p. 11, "In the case of air space construction, two additional surface coefficients for each air space must be inserted in either equation (5) or (6). These surface coefficients may be taken the same as K_1 (still air) values for the materials forming the sides of the air spaces."

Practically all engineers calculating heat losses through walls use this method of figuring.

The change in the total heat transfer by using the correct surface values may be relatively small in some cases, but may become quite important in other cases, and the determination of the correct values to use is surely worthy of the consideration of the Society.

No. 801

THE ECONOMIC THICKNESS OF BUILDING INSULATION

By M. S. WUNDERLICH,[1] ST. PAUL, MINN.

MEMBER

DURING the last quarter century great progress has been made in the heating of homes. It was not so long ago that the sleeping chambers and parts of the living quarters in a home were closed off from the heated portion. The kitchen range and a stove in the living quarters have given way to a central heating plant and with the central heating plant came the heating of the entire home. With the additional heating load there followed, of course, a decided increase in the size of heating plant and in the amount of fuel consumed per season.

Engineers have met all of the heating problems as they arose and have arrived at the size of heating plants by the experiences they received in making installations. Rule-of-thumb methods for the determination of the size of the heating plant were evolved. Some of these methods were good and some were decidedly bad; the results of their general application being that today there are many homes which are either over- or under-equipped with radiation, in whole or in part.

Among the formulae used was that of R. C. Carpenter:

$$H = \left(\frac{CN}{55} + \frac{W}{4} + G\right)(T_1 - t_0)$$

This formula has been extensively used and with much success. The formula is based on a heat transmission of 0.25 B.t.u. per sq. ft. per deg. fahr. per hr. for the wall, as is also the formula of the late J. R. Allen:

$$H = \left(\frac{W}{4} + G\right)(t_1 - t_0)\, n$$

The factors in these formulae are recognizable by the engineer. It is found that the average engineer bases the radiation on a heat loss of 0.25 for walls.

About fifteen years ago insulation, which had previously been considered only in the refrigerator field, made its entry into building construction and began to make itself felt as a factor in the field of heating. The non-insulated wall of 0.25 was covered with about $\frac{1}{2}$ in. of average insulation which has a conduc-

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Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

tivity of about 0.30. This, then, brought the heat transmission down to $K = \frac{1}{\frac{1}{0.25} + \frac{0.5}{0.30} + \frac{0.25}{0.30}} = 0.15$, when the insulation was so applied as to create the maximum number of air spaces. With the proper application, the air spaces in a wall are equivalent to about 1/4 in. of the average insulation. With this amount of insulation applied on walls and ceilings an over-all saving of about 25 per cent on fuel was realized.

With the entrance of insulation into building construction and the saving of fuel that followed, it is found that many of the leading engineers recognized the merits of the product and reduced the radiation required in proportion to the reduced heat loss. In order for the engineer to guarantee the heating plants, he sought information from the laboratories on the transmission of heat through building materials. There are a number of laboratories conducting such research and the methods of obtaining this information are almost as numerous as the laboratories conducting the work. In general, there are two methods—the hot plate and the hot box. By the hot plate method it is possible to get the conductivity through a material and this conductivity has been expressed in B.t.u. per inch of thickness per hour per degree difference in temperature. The data usually appear giving the temperature range of test, the weight of material and usually, but not always, the thickness tested. Not all of the materials used in building construction have been tested by any one research laboratory. Thus it becomes necessary to consult the data of various laboratories, correlate their work and then compute for the heat flow through built-up sections.

At this point a great deal of confusion arises. Laboratories do not all test within the same temperature range, nor do they always get a piece of material of the same manufacture that has the same thickness and density and, therefore, a different result follows. The heating engineer also raised the question as to the actual heat flow through a wall when these various materials are assembled according to average construction, realizing that the results under ideal conditions are not always attainable in practice; hence the hot box to test and check on the computed data. More confusion followed, and now the Nicholls heat meter has been perfected to measure the heat flow through the wall after the structure has been completed. This meter has great possibilities. The Code on Testing Insulating Materials developed by this Society, when used as a guide by laboratories, should clear up the existing confusion. The engineer can now look to the hot box for guidance as to the effect of the personal element in construction and as a final check on heat flow through a built-up wall, this wall being the assembly of various materials.

These data coming from laboratories are often lacking in detailed information as to the material and conditions under which the test was made. This information should be more complete. For example, consult the many conductivity tests on brick and no information is to be found regarding the brick tested which makes it possible to know if the conductivity applies to the brick under consideration.

Correct application of test data must be made by the engineer computing the heat loss. The test data give the conductance on a unit thickness but the material under consideration may not be manufactured in this thickness. One-half inch insulating materials are manufactured in thicknesses ranging from 7/16 in. to

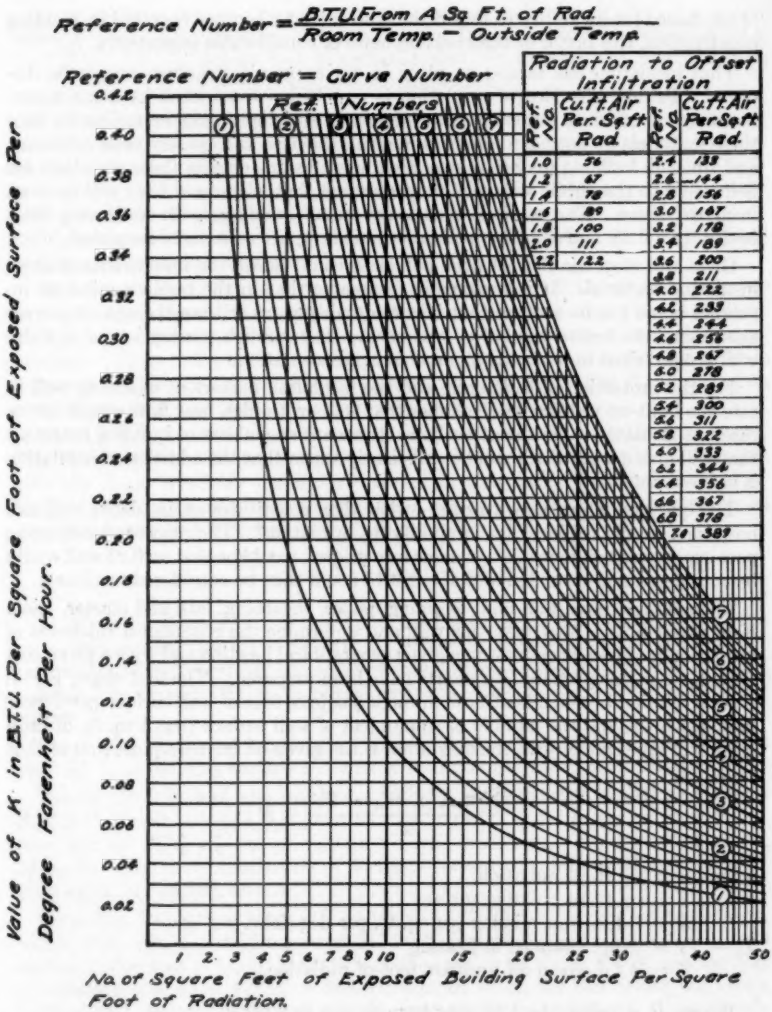


FIG. 1. RADIATION CHART BASED ON ACTUAL LOSS THROUGH BUILDING CONSTRUCTION

$^9/_{16}$ in. The thickness range then is $12^1/_2$ per cent under the nominal to $12^1/_2$ per cent over, or a total possible difference of 29 per cent. Since building insulation

is purchased for its ability to retard the flow of heat when incorporated in building construction, this factor of thickness becomes of considerable importance.

That insulation has earned its place in our economic structure cannot be disputed. In fact, the idea of insulation is now being overworked by some manufacturers of building materials. It frequently develops upon investigation that these materials do not have sufficient merit in themselves to justify their existence, and since all building materials stop heat flow to some degree, these materials are being sold to the public with the understanding that when used they will have an insulated home. The result is that today many buildings with walls very little better than 0.25, and some with a higher heat flow, are considered insulated.

Glass will stop the flow of heat but glass could hardly be merchandised as an insulating material. It is reasonable to assume that in the public's mind an insulated home means a home that is considerably warmer than the one they were accustomed to before insulation was used. The public's conception of a warm wall is equivalent to 0.25 plus $^1/_2$ in. of average insulation.

For the protection of the public and the insulation makers, it would be well to rate the built-up walls in such manner that walls with high heat flow would not be rated as insulated. On the other hand, there are assemblies of building materials that will give a wall which will be sufficiently warm that the addition of insulation is not warranted.

The question which now arises is—what then constitutes an insulated wall and how far can the engineer go in specifying insulation? The answer, based upon past experience before insulation came into its own, would be that an 0.25 wall would be considered non-insulated and about 0.15 could then be considered insulated.

The average frame wall built of siding, paper, sheathing, lath and plaster, has a K of about 0.25. Now take this wall and determine the economical thickness of insulation required when built in a given geographical location and with a given cost of fuel. For this purpose four charts have been prepared. The first chart, Fig. 1, gives a relation between heat flow through a square foot of wall surface per degree fahr. per hour, and the number of square feet of wall surface that 1 sq. ft. of radiation will take care of with the maximum B.t.u. given off from a square foot of that radiation.

$$\frac{Y \times K \times (T_1 - T_0)}{Z} = R$$

where R = sq. ft. of radiation
Y = sq. ft. of building surface
K = B.t.u. transmission per sq. ft. per deg. fahr. per hr.
$T_1 - T_0$ = temp. assumed in heating
Z = B.t.u. given off a square foot of radiation.

Where R = unity, the following formula can be written

$$Y = \frac{Z}{(T_1 - T_0)K}$$

or $$Y = \frac{\phi}{K}$$

when $\frac{Z}{T_1 - T_0} = \phi$, the ratio of the maximum B.t.u. assumed in designing for a square foot of radiation and the temperature head assumed for the maximum radiation load.

This ratio has been designated as reference number. With a B.t.u. emittance of 150 per sq. ft. of hot water radiation surface, and a temperature head of 80 deg. fahr. the reference number would become 1.88. Following the line 0.25 horizontally until it meets the reference number 1.88, then dropping perpendicularly to the bottom of the chart, 7.5 is found, which is the number of sq. ft. of building surface that 1 sq. ft. of radiation will supply. When for 1000 sq. ft. of building there would be required 133 sq. ft. of radiation.

The second chart, Fig. 2, gives a relationship between B.t.u. transmission per square foot per degree fahr. per hour, plotted as ordinates, and the loss in millions of B.t.u. per 1000 sq. ft. of building surface for the heating season, plotted as abscissa. Then following horizontally at 0.25 until the degree days of 6000 is intersected (Chicago territory), drop perpendicularly, 36,000,000 B.t.u. heat loss per 1000 sq. ft. of building surface per heating season, is found.

Chart, Fig. 3, gives a relationship between B.t.u. loss in millions, taken from Chart, Fig. 2, and cost of fuel per heating season per B.t.u. loss indicated. The curves give the B.t.u. available per $1.00 invested in that fuel. Taking hard coal at $17.00 per ton, Chicago price, and assuming that 7000 B.t.u. per pound would be available for heating purposes, as average per season, we have:

$$\frac{2000 \times 7000}{17} = 824{,}000 \text{ per } \$1.00$$

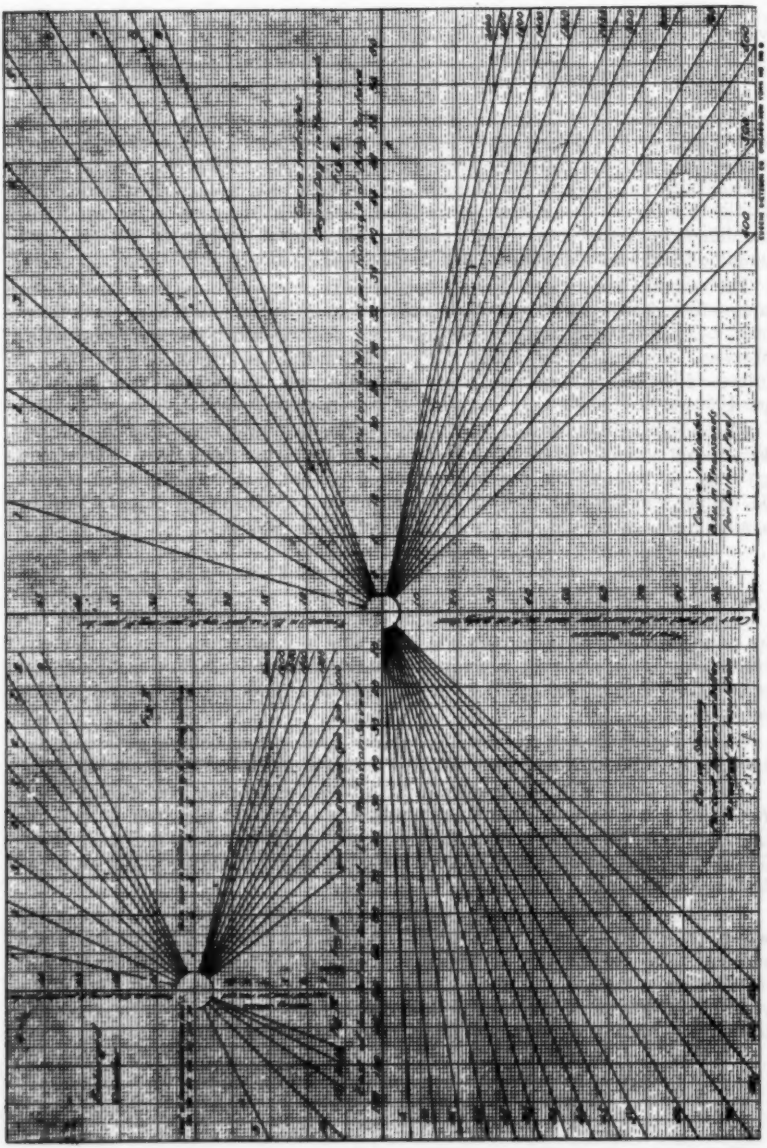
At 36 on the abscissa, which represents the B.t.u. loss in millions per season, run up perpendicularly until the 824,000 B.t.u. line is intersected, then horizontally read at the left of chart 44, which represents dollars, or $44.00 cost of $17.00 coal to offset loss through 1000 sq. ft. of building surface in Chicago territory per heating season.

Chart, Fig. 4, gives a relationship between fuel cost, in dollars, per season per 1000 sq. ft. of building surface and cost of insulation installed less radiation.

Taking the 0.25 wall and insulating with $^1/_2$ in. of average insulation giving a K of 0.15, it will be noted that there is a saving of 0.10 B.t.u. per sq. ft. per deg. fahr. per hr. The amount of radiation saved would be, from radiation chart, 53 sq. ft. The cost of radiation of 40 cents per sq. ft. would be $21.20 based on 1000 sq. ft. of building surface.

From Fig. 2 note that there is a saving of 14,300,000 B.t.u. per heating season, which, from Fig. 3, would represent $17.00 in fuel saving per 1000 sq. ft. of wall surface. The cost of $^1/_2$-in. insulation applied would be about $90.00 less the cost of radiation ($90.00 − $21.20 = $68.80), against which the fuel saving will give a yield of 24.7 per cent. So high a yield could hardly be considered the economic thickness. Adding an additional $^1/_2$ in. of insulation would give:

$$K = \frac{1}{\frac{1}{0.15} + \frac{0.5}{0.30} + \frac{0.25}{0.30}} = 0.11 \text{ or a saving of } 0.04$$



Above—Enlarged Center Section Figs. 2, 3 and 4
Below—Fig. 4. Percent Return on Dollar Invested for Insulation

Above—Fig. 2. Curve Indicating Degree Days in 1000's
Below—Fig. 3. B.t.u. in 1000's per Dollar of Fuel

From Fig. 1, radiation saved at 40 cents per sq. ft. would give a saving of 21 sq. ft. or $8.40, which leaves $90.00 − $8.40 = $81.60, to be carried against fuel saved per season. From Fig. 2, the saving would be 5,800,000 B.t.u. per 1000 sq. ft. per heating season and from Fig. 3, $7.00 per year, which return on $81.60 invested would give (Fig. 4) 8.6 per cent. Under the conditions it would not be advisable to go beyond 0.11 for an insulated wall. A higher cost of fuel than considered would naturally warrant more insulation. The author has by this method of computation shown the per cent of return on the additional insulation recommended and has been able in the gas-heated homes to approach what might be considered the economic thickness. In the gas-heated houses the estimated fuel consumption has been made so that he would know before installing the gas furnace as to the possible cost of heating. The greatest variation on our estimates does not exceed 6 per cent.

It is not always possible to get a reduction in radiation. This leads to a wide range in cost of fuel per square foot of radiation as installed and this cost with $1.00 per 1000 cu. ft. of gas ranged from 40 cents to 60 cents per sq. ft. of radiation installed. Determining fuel costs on square feet of radiation installed is correct only if the radiation has been installed according to heat loss.

An estimate to a client on the basis of square foot of radiation installed would, on 1000 sq. ft. of radiation, make a difference of $100.00 if 50 cents were the basic cost. On an actual $400.00 fuel cost this would be 20 per cent, which is a determining factor in the kind of fuel. With insulation it is possible to get the comforts and conveniences of more expensive fuels within the economic range of many more home owners.

The economic thickness of insulation depends upon the following factors:

1. Cost of fuel available for heating.
2. Seasonal demand.
3. Cost of insulation installed.

These factors are variable and must be worked out for each locality. There will be a slight fluctuation in the cost of fuel from season to season.

The computations, Table 1, have been determined for the economic thickness of insulation for a locality of 6000 degree days, hard coal $17.00 per ton, coke $12.50 per ton and bituminous coal $9.00 per ton, and a cost of $90.00 per 1000 sq. ft of $^1/_2$-in. insulation and $130.00 per 1000 sq. ft. of 1-in. insulation applied. Where 1-in. insulation is applied in the side walls, $15.00 per 1000 sq. ft. is added to take care of additional depth of window and door frames, the insulation being installed to take advantage of air spaces and having conductance of 0.30 per unit inch.

From these computations it will be observed that the saving with 1-in. insulation in the ceiling, with $17.00 per ton coal, is slightly greater than the saving with $^1/_2$-in. insulation in the side walls, and that with $9.00 per ton coal the saving with 1-in. insulation in the ceiling is slightly less than the $^1/_2$-in. insulation in the side wall, while with $12.50 per ton coke the saving is the same. This would indicate that with a higher fuel cost the insulation in the ceiling should be increased over that indicated as compared with side walls, and that with $9.00 per ton coal the thickness of the ceiling insulation approaches the thickness of insulation of the side wall. Therefore, it follows that with the average cost of fuel to the home owner that the

TABLE 1. COMPUTATIONS FOR DETERMINING THE ECONOMIC THICKNESS OF INSULATION IN MIDDLE WESTERN LOCALITY

	Walls			Ceilings		
	I	II	III	I	II	III
Construction taken as base	A	B	B	E	F	F
	0.25	0.15	0.15	0.28	0.13	0.13
Insulation added	B	C	D	F	G	H
	0.15	0.11	0.12	0.13	0.10	0.11
Saving in B.t.u. per sq. ft. per °F. per hr.	0.10	0.04	0.03	0.15	0.03	0.02
Sq. ft. of radiation saved, Fig. 1	53	21	16	74	16	11
Saving in radiation at 40 cents per sq. ft.	21.20	8.40	6.40	29.60	6.40	4.40
B.t.u. saved in millions per heating season, Fig. 2	14.3	5.8	4.3	21.5	4.5	2.5
Saving in fuel per M sq. ft. building surface per heating season using $17.00 per ton coal, Fig. 3, 824,000 B.t.u. per $1.00	17.00	7.00	5.20	26.50	5.00	3.00
Cost of insulation applied	90.00	90.00	145–90	130.00	90.00	130–90
Saving in radiation	21.20	8.40	6.40	29.60	6.40	4.40
Investment in insulation. (Cost of ins. applied less radiation)	68.80	81.60	48.60	100.40	83.60	35.60
Return on money invested in ins., Fig. 4	24.7%	8.6%	10.6%	26.3%	6.0%	8.4%
Saving in fuel per M sq. ft. building surface per heating season using $12.50 per ton coke, Fig. 3, 1,120,000 B.t.u. per $1.00	13.00	5.40	3.90	19.00	4.00	2.50
Return on money invested in ins., Fig. 4	18.9%	6.6%	8.0%	18.9%	4.8%	7.0%
Saving in fuel per M sq. ft. building surface per heating season using $9.00 per ton coal 1,556,000 B.t.u. per $1.00	9.75	3.80	2.80	14.00	2.80	1.50
Return on money invested in ins., Fig. 4	14.1%	4.7%	5.8%	13.9%	3.3%	4.2%

A = Siding, building paper, sheathing, wood lath and plaster.
B = Wall A with $^1/_2$″ average insulation installed to create 2 air spaces.
C = Wall A with 2 layers of $^1/_2$″ average insulation installed to create 3 air spaces.
D = Wall A with 1″ average insulation on face of studs furred out for lath and plaster.
E = Wood shingles, paper, roof boards, wood lath and plaster.
F = Ceiling E with 1″ average insulation furred down for wood lath and plaster.
G = Ceiling F with an additional $^1/_2$″ average insulation installed to create an additional air space.
H = Ceiling E with 2″ of average insulation.

ratio of $^1/_2$-in. insulation in the side walls to 1-in. insulation in the ceiling is a well-balanced insulated job.

The above costs for insulation installed are average costs from contractors in Chicago territory for various insulations.

The savings through side walls and ceilings are based upon inside temperature of 70 deg. fahr. and do not take into consideration the temperature difference which exists between the floor and ceiling, which in a non-insulated home are appreciable. A consideration of this temperature difference adds to the advantage of heavier insulation for the ceiling. Another advantage of insulation is the fact that temper-

ature in well-insulated homes is very uniform and, further, it is possible to maintain higher humidities without condensation upon the wall and ceiling surfaces.

Higher humidities adding to the health and comfort of the family also increase the life of the household equipment. A greater comfort is also experienced during the summer season when living quarters and sleeping chambers are cool and refreshing instead of warm as an oven.

DISCUSSION

E. R. POWELL[2] (WRITTEN): The writer's point of view in building insulation is, of course, entirely different from that of Mr. Wunderlich's due to the entirely different sort of insulation recommended by our Company. We think it fair, however, that the public should get both points of view, or at least be advised that two such points of view exist.

In regard to the economic thickness of building insulation, we have proved to our own satisfaction, that the most economic thickness is $3^1/_2$ to $3^3/_4$ in., or the thickness of the studding of the building wall. If a 6-in. studding is used, we recommend that the entire wall space be filled with insulation because it is less expensive to fill this space than to put in an inner wall so that a lesser thickness may be used. For ceilings we recommend an insulation thickness about equal to that in the walls.

Our reason for recommending this insulation thickness is that a bulk insulation seems to us to have an overwhelming advantage over the sheet or felt form, with which it is in competition. The wall of a frame house forms, without any additional attention, a perfect space into which insulation may be poured or packed with the greatest convenience. The conductivity of our insulation, according to U. S. Bureau of Standards tests, is about 0.275. By packing the entire wall space with this extremely efficient insulation, wall radiation is reduced to only a small part of what it is in an uninsulated house. As a general average, we find that the wall radiation is reduced by 80 per cent. That is, only 20 per cent of the original loss is still transmitted through the wall.

The cost of this method of insulating frame buildings compares very favorably and is in many cases lower than the cost of even a $^1/_2$-in. of sheet or felt insulation. We, therefore, can hardly agree with Mr. Wunderlich's conclusion that the economic thickness for wall insulation is often about $^1/_2$ in., and for ceiling insulation about 1 in. By packing the walls solid, a perfect wind break is formed against infiltration through the cracks in spite of any reasonable amount of shrinkage and warping in the lumber. This insulation is a perfect electrical insulation also and cannot cause any trouble from the wiring. If the pipes are run close to the inner wall, it is positive prevention of all freezing trouble. Furthermore, the fire channels in the wall are positively stopped with a mineral non-combustible material, so that by actual tests it is possible to burn the lath off the inside of a room before the fire spreads to another room.

Another portion of Mr. Wunderlich's article in which we disagree very decidedly, is the statement in regard to glass. To quote it exactly, "Glass will stop the flow of heat, but glass could hardly be merchandised as insulating material." We find that the conductivity of glass is about 50 as compared to our material of 0.275. In other words, glass could not ordinarily pass as an insulator at all. In fact, the

[2] Chief Engineer, Banner Rock Products Co., Alexandria, Ind.

heating engineers, with whom the writer is acquainted, figure the radiation from the glass surfaces at a much higher rate than the rest of the wall.

Another statement, "There are assemblies of building material that will give a wall which will be sufficiently warm that the addition of insulation is not warranted," which I believe is likely to leave an erroneous impression. It may be that the arrangement of building material may be such that an expensive insulation would not be justified at the present price of coal. On the other hand, we are buying insulation now and saving fuel in the years to come. Also, due to the increased comfort and convenience of gas and oil for house heating, their use is being rapidly extended. When these more expensive fuels are involved the necessity for a real insulation comes to the fore. If there is any arrangement of common building material, which would obviate the necessity for insulation in a gas-heated house, such has never come to the writer's attention and he would be much interested to know what it is. In working with some of the gas companies, we find they recommend our insulation, and will guarantee the gas bill if our insulation is used.

M. S. WUNDERLICH (WRITTEN): I do not agree with Mr. Powell that we hold different viewpoints on the economic thickness of insulation. It is simply a case of figures. The purchaser of the insulation is the judge and must decide what return he demands on money invested which, of course, will depend upon what return he can secure with equal safety of principle in the money market as compared to the investment in his home.

Mr. Powell states that $3^1/_2$ in. is the economic thickness when Hominsul is used, but he does not state what the cost of this insulation applied is nor does he show the return on investment with different costs of fuel. It is true we build for the future, but I cannot see any justification in recommending as much insulation for the man who burns $9.00 per ton fuel as compared with the man who burns gas at the rate of $1.00 per 1000 cu. ft., especially when the man with $9.00 per ton coal lives in a 5000 degree day heating season while the $1.00 per 1000 cu. ft. of gas is consumed in a 9000 degree day locality and the cost of insulation applied is the same. Any insulation will not most conveniently adapt itself to all conditions. Mr. Powell gives the conductivity of Hominsul as 0.275 but does not give the density. It is important that the density as given for the conductivity be the density of the material in the filled space. If a different density is obtained a different heat flow will result. As pointed out in the paper, this is one of the numerous items to be watched. A finished product from the factory has the advantage of controlled density over that which is assembled on the job.

In reference to glass stopping the flow of heat. The formula given in the paper gives the transmission of glass as 1.00. The *Heating and Piping Contractors' National Association* gives the transmission for single sash as 1.1 and for double sash 0.6. Mr. Powell certainly must have had the experience of materials of so high a heat flow being sold as insulation. I still contend that a material with so high a heat flow should not be merchandised as insulating material, although when used it will retard the flow of heat. Without the proper heat transmission constants we could not have computed the heat loss for the last 12 to 15 years to so close a degree, as the greatest variation for gas consumed of 6 per cent on the estimate.

There are few insulations that have not been recognized by gas companies.

There are also gas companies who have installed gas-fired boilers in homes where there was no insulation. The paper does not state that there are building assemblies of gas-heated homes that do not require insulation, but I would not be surprised if in the natural gas localities, where the heating load is small and gas cheap that this was actually the case. I have found building construction having a heat transmission of 0.13 without insulation (also given in THE GUIDE) and located in a 4000-degree locality and where the fuel burned was $5.00 per ton. When considered purely from the fuel-saving standpoint, there was no form of insulation that could be justified. Again, the economic thickness of insulation depends upon: 1. Cost of fuel available for heating; 2. Seasonal demand; 3. Cost of insulation installed. This applies to any and all types of insulation. The curves are intended to make computation on the B.t.u. basis quickly and accurately.

Mr. Powell makes reference to decreased infiltration. It is true that an insulated house is tighter than a non-insulated house, but it is also true that when there has been an effort to insulate, the building is built tighter. We have no authentic information on the air leakage through various insulated and non-insulated walls, so cannot take this factor into consideration in making our computations.

The matter of fireproofness: Most all insulating companies claim fire-retarding properties for their material. The Burlington fire-proof office building gutted by fire in Chicago, Engineering News, Vol. 88, report of investigating engineers proved that the contents of the building was the all-important factor. Fire-proof material in frame construction will not prevent a building from burning or lower the insurance premium.

T. S. TAYLOR: I would like to ask a question at this point that may or may not be out of place. I would like to know whether Mr. Wunderlich or Mr. Sanbern have any information which would give us the coefficient which you would have, say, for an ordinary brick veneer dwelling. In other words, with the ordinary method of studs and plaster inside, the sheeting, followed by paper and brick veneer on the outside, what would be the coefficient of heat transfer for this type of structure?

MR. WUNDERLICH: In answer to Mr. Taylor's question, I haven't the data with me but we have computed the heat transmission through that type of wall. If my memory serves me right it is about 0.21. That would change your final results that I have given you. The economic thickness must be worked out for each case.

MR. TAYLOR: Again what would you figure it would be if you filled up all the space between the studs with material that had the same thermal conductivity as wood itself? In other words, you cut out all the air space between the studs.

MR. WUNDERLICH: I can compute that for you, but I do not have the transmittance coefficient at hand.

No. 802

UTILITY DEMANDS OF A MODERN HOSPITAL

By G. L. LARSON[1] (*Member*), D. W. NELSON[2] AND R. A. ROSE[3] (*Non-Members*)

Introduction

WHEN the Wisconsin General Hospital building (Fig. 1) here described was being designed, the engineers responsible for the layout of the mechanical equipment were handicapped on account of the lack of published data on the utility demands of such a building. Data were either not available or so conflicting as to render them useless or of very doubtful value. Different authorities disagreed to a wide degree. Most of the published values were found to be average daily or average monthly values and practically no information was found referring to the peak load that might be expected in a building of this type. This was especially true in reference to the demands for hot, cold and soft water. Reliable demand data on which could be based the selection of sizes of hot water heaters, water softeners, booster pumps, ice-making plants and other equipment were not to be found.

In view of this scarcity of published information, meters were installed as a part of the building equipment and a careful investigation of the utility demands has been made for a period covering sixteen months.

It is hoped that the data here published will prove of value to architects and engineers employed in the design of similar buildings.

Description of Hospital

At the special session of the Wisconsin Legislature in 1920, the establishment of the Wisconsin General Hospital was authorized in connection with the Medical School of the State University and is under control of the University Board of Regents.

The total amount appropriated for a hospital building, for a residence for nurses, and for equipment, was $1,350,000. Additional sums were appropriated for the purchase of land. The hospital was erected as a memorial to those who served in the World War. Its purpose is to supplement the existing resources of the state for care of patients, for education of physicians and nurses and for the advance of medical knowledge.

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Presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, New York, N. Y., January, 1928.

An act passed by the Legislature defining the purposes of the hospital and providing for its support makes it mandatory for public officials and physicians, and advisable on the part of others especially interested in the public welfare, to report to the county judge those patients who appear to need its care. The act at the same time makes ample provision for transportation and care, at joint county and state expense, of patients who, upon further investigation, are found to need such care and are likely to benefit from the treatment afforded at the hospital. Provision is also made for patients who can afford to pay for cost of hospital care and who are in need of special facilities not readily obtainable in their local communities.

FIG. 1. WISCONSIN GENERAL HOSPITAL

Although the Wisconsin General Hospital has been available for care of patients for only about three years, its need has been amply demonstrated. With a total capacity of about 300 beds, there are usually from 260 to 275 bed patients within its walls and at times every bed is filled.

Mechanical Equipment and Engineering Features

The building, which was designed by Arthur Peabody, State Architect, has six stories and a basement and in addition has a number of rooms on the roof which are used for patients requiring open air treatment. It is built of brick, with stone facings and cornices, and is of fire proof construction. The building contains about 380 rooms, has a gross floor area of 132,000 sq. ft. and a gross cubical content of 2,000,000 cu. ft. Fig. 2 shows a layout of the mechanical equipment.

Ventilation

The ventilation of patients' rooms is by open window supply. A special type of window is used in which the air is admitted at the cross bar of the sash, or at the top or at both places. The sash draws inward like a transom and the air flows upward without striking the patient. All toilet rooms, bath rooms, utility rooms and certain special treatment rooms, have mechanical exhaust ventilation by means of four exhaust fans on the roof. Except for the air supplied by one fan to several lecture rooms on the sixth floor, there is no fresh air supplied to the building by mechanical means.

Heating System

Of the 88 buildings connected to the central steam heating plant of the University, this hospital is one of three buildings that is heated by hot water. The system is a down feed type with forced circulation. The building contains 36,000 sq. ft. of hot water radiation which gives 55 cu. ft. of gross space heated for each square foot of radiation.

The circulating pumps for the heating system are in duplicate, each being capable of handling the entire load. Each pump which has a rating of 600 gal. per min. is driven by a $7^1/_2$ h.p. motor. This gives a circulation of one gallon of water per hour for each square foot of hot water radiation installed.

The water is heated by low pressure steam from the central plant and the heaters are in duplicate, each being capable of heating 36,000 gal. per hr. from 170 to 190 deg. when supplied with steam at 3 lb. pressure. These heaters are the usual shell and tube type with the water passing through the tubes.

The water for the hot water services of the building is heated by heaters of the same type. These are also in duplicate, each having a capacity of heating 2000 gal. per hour from 50 to 180 deg. when supplied with steam at 5 lb. pressure. The storage tank has a capacity of 1200 gal. For circulating the hot water to the various fixtures in the building, duplicate pumps are used. Each has a capacity of 90 gal. per min. and is driven by a 3 h.p. motor. Either pump may also be used as a booster pump if the city water pressure drops to a point where boosting is necessary.

Water Softeners

Due to the fact that Madison city water has hardness of about 22 grains per gallon, all hot service water is softened. There are two Zeolite units installed, each having a softening capacity of 24,000 gal. in 24 hrs. with a maximum rate of softening of 4000 gal. per hr. Under the average condition of operation, it is necessary to regenerate each unit once per 24 hrs. A considerable amount of water is used in flushing these softeners and the total water per patient used in this building will, therefore, be greater than the amount to be expected in a building not having softeners. It should also be noted that there is no laundry in connection with this building and allowance will have to be made for additional water consumption when a hospital with a laundry is considered.

This building has two sources of water supply. The cold water to all toilets, utility closets, slop sinks and hose bibs is termed "lake water" and is supplied from Lake Mendota by the University pumping station. All other water used is

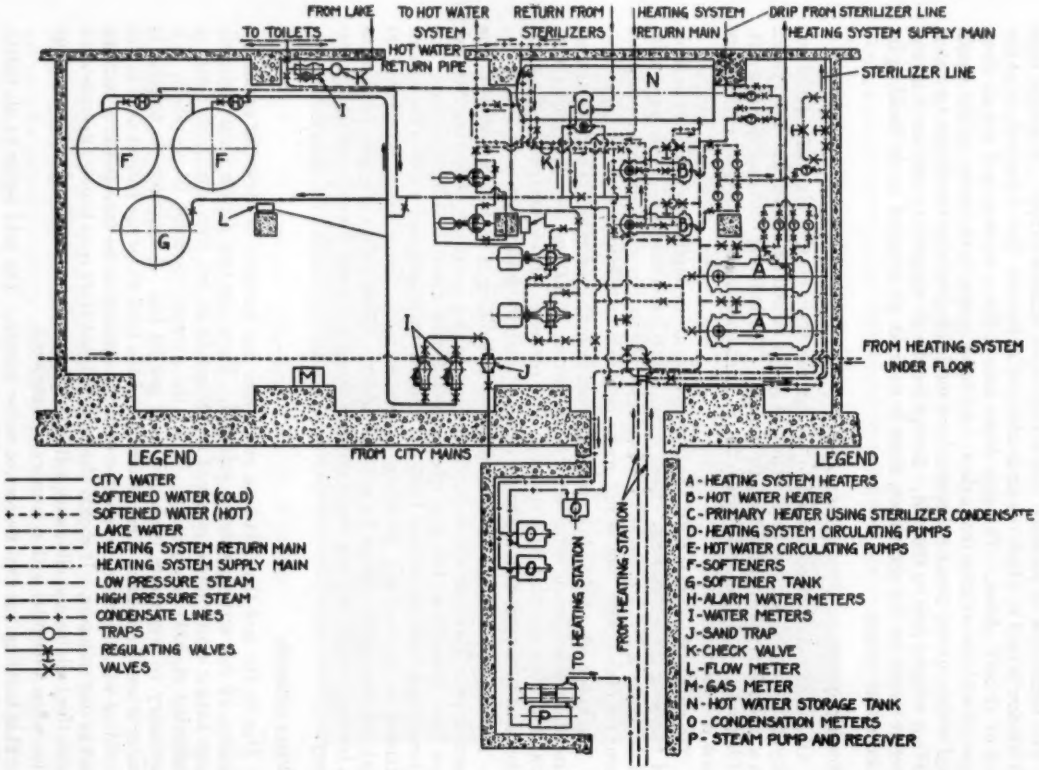


FIG. 2. LAYOUT OF MECHANICAL EQUIPMENT AND POSITION OF WATER METERS IN WISCONSIN HOSPITAL

supplied from the city mains and is termed "city water." None of the "lake water" is heated, and only "hot water" is softened.

Refrigeration System

Installed in the basement of the building is a 15-ton capacity motor-driven carbon dioxide refrigerating machine. This machine has an ice-making capacity of thirty 60-lb. cakes of ice per day in addition to the capacity necessary to cool the cold storage rooms adjacent to the main kitchen, and to cool the seventeen small boxes in the diet kitchens and other parts of the building.

There are two major electrical circuits. One circuit supplies the current for

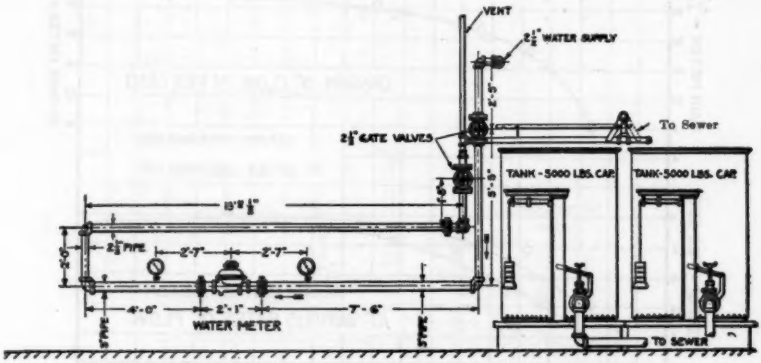


FIG. 3. APPARATUS USED IN TESTING WATER METERS

lights, physio-therapy apparatus, x-ray machines and the small motors that are usually connected to lighting circuits. The other circuit supplies power to elevators, pumps, fan motors, refrigerators, etc. There are two passenger elevators and a service elevator.

In the central heating station of the University, there is installed a turbo-generator for the exclusive service of the hospital in case the usual source of power fails.

Scope of Observation

Daily readings were taken of the following: city water, hot water, lake water, steam for heating hot water, steam for heating building, ice produced, city gas and electricity used for lighting and for power. The location of the various meters installed is shown in Fig. 2.

As noted before, water for all purposes other than for flushing toilets, slop sinks and for utility closets, is purchased from the municipally-owned water system of Madison. Main reliance for measuring the city water used was placed on the two 3-in. compound type water meters installed by the water department for billing purposes. The meters were installed in parallel and only one was in service at a

time, the other being held in reserve in case the one needed to be removed for repairs or testing. An electrically-operated flow meter, installed on this line, served as a check on the continued accuracy of the compound water meters and gave a means of studying the distribution of the load during the day.

The city water divides into two lines, one of which carries water to the softeners, then through the heaters to the storage tank as hot water; the other continues as the cold water line. Each softener is equipped with an alarm meter of the disc type for indicating the need for recharging. Daily readings were taken on each of these meters to determine the hot water used. A mechanically-operated flow

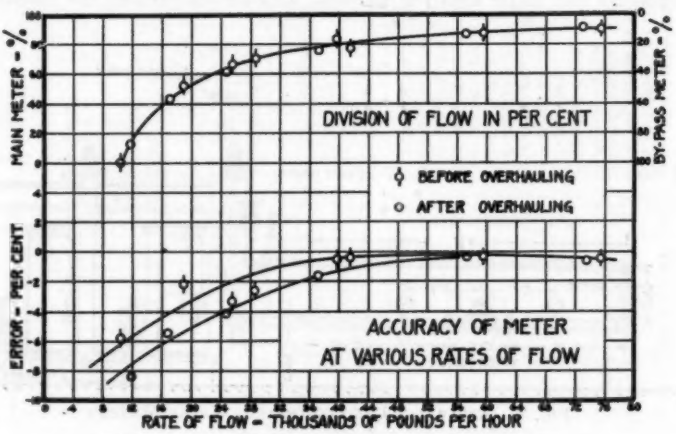

MAIN METER - %
BY-PASS METER - %
DIVISION OF FLOW IN PER CENT
BEFORE OVERHAULING
AFTER OVERHAULING
ERROR - PER CENT
ACCURACY OF METER
AT VARIOUS RATES OF FLOW
RATE OF FLOW - THOUSANDS OF POUNDS PER HOUR

FIG. 4. CHART SHOWING RESULTS OF METER TESTS

meter of the orifice type was also installed in this line as a check, and to give a graphic record of the daily distribution of load.

The university pump house, located on the campus and on the shore of Lake Mendota, furnishes lake water for the rough uses previously mentioned. A 3-in. compound water meter of a type similar to those on the city water supply was installed on this line. No duplicate meter, however, was put on this line, consequently when this meter was in need of repair, or was removed for testing, readings on the lake water were temporarily discontinued.

The steam furnished by the central heating station of the University is measured by condensation meters of the bucket type. The steam used for heating the hot water of the heating system, after leaving the heaters as condensate, flows by gravity into two condensation meters placed in parallel, each having a capacity of 12,000 lb. per hr. The inlets to the meters were not valved so that both meters registered about the same flow and neither was overloaded at periods of maximum demand.

The steam used for heating softened water likewise flowed as condensate into

a condensation meter by gravity. The capacity of this meter was 6500 lb. per hr. The condensate from the various sterilizers, 54 in all, and from the steam-cooking apparatus, returning at a temperature of about 300 deg. fahr. is cooled to about 180 deg. fahr. by being circulated through a small heat-exchanger that serves at the same time, as a primary heater for the softened water on its way to the hot water heaters. Unfortunately for data-taking purposes, the condensate from the sterilizers and cooking apparatus joined that which returned from the hot water heaters, and could not be metered independently without involving extensive changes in the piping system. The modification of the existing arrangement was not thought to be worth while, especially in view of the fact that the amount of

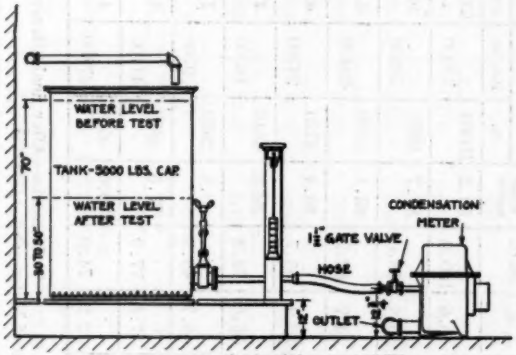


FIG. 5. APPARATUS FOR TESTING CONDENSATION METERS

steam used for heating the water for the hot water supply can be calculated readily from the steam pressure, condensate temperature and the initial and final temperatures of the water.

The quantity of ice produced, which is used only in the form of cracked ice, was determined by keeping a record of the number of cans of ice taken out of the freezing tank each day. The cans are of 60-lb. capacity, but the filler float was adjusted to give 55-lb. weight cakes.

The quantities of electricity and gas used were measured on the meters belonging to the public utility company furnishing these items. The electrical load is divided between two meters, one for the power load and one for the lighting load. The lighting load, as before mentioned, includes, besides lights, the x-ray machines, and physio-therapy apparatus such as ultra-violet ray machines. No tests were made on these meters except the routine tests of the utility company.

Method of Testing Meters

The water meters used for measuring city water, hot water and lake water were removed and tested frequently enough to insure their accuracy throughout the

TABLE 1. TEST OF A WATER METER

Where Used—State Hospital City Water (East) No. 1
Remarks—Before Inspection and Repairing

Date—March 7, 1927, Type of Meter—Compound Hersey, No. of Meter—No. 1,039,074

Valve opening inches	Elapsed time, min.	Pressure before meter, lb./sq. in.	Pressure after meter, lb./sq. in.	Main meter dial reading	Main meter, cu. ft.	By-pass dial reading	By-pass meter, cu. ft.	Total flow, cu. ft.	% Carried by main meter	Total flow by meter		Actual wt.		Difference metered and weighed	% error
										lb.	lbs./hr.	lb.	lbs./hr.		
3	8.0	18.0	15.0	2,223,507.9 2,223,363.7	144.2	053,807.3 053,791.5	15.8	160.0	90.2	10000	75000	10028	75500	−28	−0.36
1¼	10.0	32.0	28.0	2,223,646.5 2,223,507.9	138.6	053,826.7 053,807.3	19.4	158.0	87.7	9870	59250	9925	59500	−55	−0.55
1⅛	7.83	30.0	28.0	2,223,880.0 2,223,811.7	68.3	053,868.9 053,855.0	13.9	82.2	83.1	5140	39400	5161	39600	−21	−0.42
1	10.0	39.0	34.0	2,223,923.6 2,223,980.0	43.6	053,891.0 053,868.9	22.1	65.7	66.4	4120	24700	4242	25452	−122	−3.5
15/16	15.0	44.0	39.0	2,223,962.2 2,223,923.6	38.6	053,926.6 053,891.0	35.6	74.2	52.0	4640	18550	4741	18964	−101	−2.1
⅞	18.0	60.0	52.0	2,223,962.4 2,223,962.2	0.2	053,973.3 053,926.6	46.7	46.9	0.4	2930	9760	3102	10360	−172	−5.5
1 1/16	7.1	50.0	43.0	2,224,022.8 2,223,962.4	60.4	053,990.8 053,973.3	17.5	77.9	77.5	4860	41100	4887	41300	−27	−0.55
15/16	10.0	56.0	49.0	2,224,074.6 2,224,022.8	51.8	054,013.0 053,990.8	22.2	74.0	70.0	4630	27800	4750	28500	−120	−2.53

Remarks—After final alteration was made

Date—March 21, 1927, Type of Meter—Compound Hersey, No of Meter—No. 1,039,074

3	4.20	18.0	15.0	0,000,605.0 0,000,530.2	74.8	000,163.0 000,156.0	7.0	81.8	91.5	5110	73000	5149	73500	−39	−0.76
1⅛	5.10	39.0	34.0	0,000,672.5 0,000,605.0	67.5	000,173.1 000,163.0	10.1	77.6	86.9	4850	57100	4867	57300	−17	−0.35
1	6.00	53.0	46.0	0,000,716.8 0,000,672.5	44.3	000,187.7 000,173.1	14.2	58.5	75.7	3658	36580	3716	37160	−58	−1.56

15/16	7.00	60.0	54.0	0,000,744.1 0,000,716.8	27.3	000,204.0 000,187.3	16.7	44.0	62.1	2750	23580	2873	24600	−123	−4.30
15/16	10.0	58.0	50.0	0,000,530.0 0,000,511.5	18.5	000,155.9 000,131.9	24.0	42.5	43.5	2660	15980	2812	16880	−152	−5.40
7/8	10.0	64.0	56.0	0,000,747.8 0,000,744.1	3.7	000,229.1 0,00204.0	25.1	28.8	12.9	1890	10800	1966	11790	−166	−8.45

TABLE 2. TEST OF A CONDENSATION METER

Meter Test

Date—May 21, 1927
Type of Meter—Cadillac Condensation
No. of Meter—G 26781, Capacity 12,000 Lb. per Hour

Where Used—Steam for Heating State Hospital
Remarks—

Valve opening turns	Elapsed time, min.	Head before test, in.	Head after test, in.	Main meter dial reading	Total flow by meter		Actual weight flow		Difference metered and weighed, lb.	% error
					lb.	lb./hr.	lb.	lb./hr.		
6 1/4	10	70	38	0,640,900 0,638,300	2600	15600	2725	16350	−125	−4.6
5 1/4	10	70	38	0,643,550 0,640,980	2570	15420	2700	16200	−130	−4.8
4 1/4	11	70	38	0,646,210 0,643,550	2660	14520	2740	14950	−80	−2.9
3 1/4	13	70	39	0,648,830 0,646,210	2620	12090	2670	12320	−50	−1.9
2 3/4	12	70	45	0,650,980 0,648,830	2150	10750	2130	10650	+20	+0.9
2 1/4	12	70	51	0,652,610 0,650,980	1630	8150	1650	8250	−20	−1.2
2.0	12	70	54	0,653,000 0,652,610	1390	6950	1370	6850	+20	+1.5
1 7/8	12	70	57	0,654,110 0,653,000	1110	5550	1090	5450	+20	+1.8
1 5/8	12	70	59	0,656,100 0,654,110	990	4950	960	4800	+30	+3.1

sixteen months' period of data taking. Fig. 3 shows the apparatus used in testing these meters.

Tests were made at various rates of flow over the range of the meter when not exceeding the capacity of the $2^1/_2$-in. line supplying the test apparatus. During tests, the valve on the supply line was kept wide open. The valve on the discharge line was opened a certain distance, as measured by the rise of the stem, sufficient to give the flow wanted, and the time was then noted. When the amount of water considered necessary to give an accurate test had been run into the tanks, the valve was shut, and the time again noted. The flow as determined by the meter readings taken before and after the test was then compared with the weighed flow. Table 1 shows the test data of a compound water meter of the current and disc type before and after overhauling by the city water department. This double testing was done

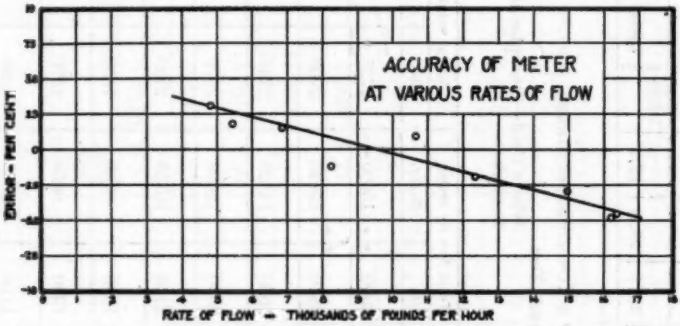


FIG. 6. CHART SHOWING GRAPHIC RESULTS IN TESTING CONDENSATION METERS

in every case of overhauling to have a record of the accuracy of the meter both before its removal for overhauling and after its replacement. Fig. 4 shows graphically the test results, the upper curve indicating the distribution of the flow in the compound meter at various rates, between the main meter, which was of the current type, and the by-pass meter, which was of the disc type.

On a preliminary test after overhauling, it was found that this meter registered 50 per cent or less of the flow at light loads although very accurate at high loads. This was traced to too small a clearance on the current wheel so that on light flows the main meter registered no flow. When this friction was removed the results labeled as "after overhauling" were obtained. In this case, the characteristics of the meter after overhauling were the same as before; that is, the highest degree of accuracy was at high rates of flow, with a gradual decrease in registration at low rates of flow. The decreased registration at light flows might be due to friction on the current wheel, to friction on the disc of the by-pass meter, or to excessive clearances between the disc and body caused by wear.

In some instances the meters registered more than the correct flow. Mechanisms having a certain gear ratio are installed in the meter; in case of low registration due

to wear, a mechanism of a slightly different gear ratio is often installed to correct the registration. This method of adjustment is as likely to result in slight over-registration as it is in under-registration.

The apparatus for testing the condensation meters is shown in Fig. 5 while Table 2 gives the test results for one of these meters. Fig. 6 shows these results graphically. In testing, the tank of 5000-lb. capacity was filled and weighed. The test run was then started by opening a certain number of turns the $1^1/_2$-in. valve on the line going to the meter, and noting the time. When sufficient water had run through for an accurate test, the valve was shut and the time noted, and the amount of water was determined by difference of weights before and after. The head varied in each test run from 70 in. to about 30 to 50 in. so that the flow rates

TABLE 3. DAILY QUANTITIES—AVERAGE AND MAXIMUM AMOUNTS USED PER DAY

MONTH	CITY WATER GALLONS		HOT WATER GALLONS		LAKE WATER GALLONS		STEAM FOR H&W POUNDS		STEAM FOR ELEC. POUNDS		ICE MADE POUNDS		ELEC. FOR LIGHT KILOWATTS		ELEC. FOR POWER KILOWATTS		CITY GAS CUBIC FEET	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
JANUARY '26	—	—	—	—	—	—	30500	35300	81300	119000	—	—	663	790	549	600	4052	5100
FEBRUARY	64170	77600	15368	21300	6786	9560	30300	34700	71200	88500	1298	1585	645	770	540	600	3979	5100
MARCH	60244	85000	16886	26700	7556	11050	29600	41700	74270	104300	1386	1650	599	670	544	630	4096	5200
APRIL	62347	77000	19057	21600	7207	10380	30200	34500	56200	61100	1424	1650	518	690	520	600	4200	5200
MAY	61102	82600	17516	20400	6417	10440	28040	31900	21110	69200	1518	1650	518	620	457	570	3945	5300
JUNE	48662	65650	15390	17400	3963	6290	24800	29400	7670	52000	1705	1980	482	610	453	540	3920	6100
JULY	56900	82400	16129	17800	—	—	24870	27700	454	11600	1567	1650	455	590	477	510	3513	4500
AUGUST	59611	75060	15555	17300	7586	15250	24840	27400	248	7300	1562	1650	481	620	496	620	3842	4800
SEPTEMBER	75573	92500	15447	17400	7703	16100	25500	31800	20800	59300	1551	1650	555	690	504	570	4070	5200
OCTOBER	96842	116500	18870	23200	8302	11940	28220	34600	38160	67300	1485	1485	640	750	564	680	4293	5800
NOVEMBER	87840	119600	20207	23350	8561	11110	32570	37600	68400	95400	1520	1485	722	840	586	670	4610	7900
DECEMBER	61097	94000	22548	25300	7803	10940	31450	33900	69400	89600	1650	1650	753	860	527	580	4577	6200
JANUARY '27	63276	96800	22645	24300	6529	10006	30850	40600	81070	131200	1578	1650	729	830	523	580	4520	5700
FEBRUARY	61737	92200	23200	26500	5947	12900	33700	57900	63000	87600	1485	1485	724	870	557	610	4871	6100
MARCH	64426	97500	22345	25000	9229	10620	37200	41700	56000	68600	1485	1485	720	900	536	620	5039	6500
APRIL	64610	116500	21907	25000	8394	10620	35300	39800	46800	67900	1616	1650	669	800	521	660	5140	6400
AVERAGE FOR 18 MONTHS [a]	64525	90375	20698	24051	6435	11630	29795	34525	42928	68233	1544	1623	621	748	517	601	4362	5825

[a] MAY 1926 TO APRIL 1927, INCL. [b] AVERAGE FOR EIGHT MONTHS — SEPTEMBER 1926 TO APRIL 1927 INCL.

used were average. The tests on all three meters showed the same characteristics of increased registration at low rates of flow. The test results are given for water at approximately 60 deg. fahr.; the temperature of the condensate handled by the meters is approximately 170 deg. fahr. Correcting for differences of specific volume the test shows that the meter read 2.5 per cent high. The capacity of this meter was 12,000 lb. per hr., but it proved capable of handling an overload with no material drop in accuracy.

It was considered essential to test all meters at various rates of flow, since the accuracy in most cases varied considerably with the flow, as shown in Figs. 4 and 6. The two disc type water meters originally on the water softeners were found to be reasonably accurate at high rates of flow, but at low rates registered only about 50 per cent of the flow. These meters were replaced by new ones which tested satisfactorily. Fig. 4 shows the test results for one of the less accurate of the meters used. The registration of this meter corresponding to average rates of flow in service was about 3 per cent low. No attempt was made to correct recorded flows for the

TABLE 4. DAILY QUANTITIES—AVERAGE AND MAXIMUM AMOUNTS USED PER PATIENT DAY

MONTH	CITY WATER GALLONS		HOT WATER GALLONS		LAKE WATER GALLONS		STEAM FOR H.W. POUNDS		STEAM FOR BLDG. POUNDS		ICE MADE POUNDS		ELEC. FOR LIGHT KILOWATTS		ELEC. FOR POWER KILOWATTS		CITY GAS CUBIC FEET	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
JANUARY '26	—	—	—	—	—	—	121	157	321	451	—	—	2.62	3.07	2.16	2.51	16.0	20.4
FEBRUARY	252	318	60.5	80.0	26.6	37.6	119	141	281	356	5.10	6.32	2.54	3.09	2.12	2.34	15.7	20.1
MARCH	227	318	71.0	101.0	23.5	39.7	113	156	280	396	5.22	6.27	2.26	2.54	2.03	3.16	15.4	20.2
APRIL	239	310	72.5	83.5	27.3	36.9	115	126	214	302	5.44	6.82	1.98	2.85	1.98	2.36	16.1	21.5
MAY	252	322	66.4	79.0	24.3	39.6	106	121	80	262	5.77	6.49	1.96	2.31	1.75	2.14	14.9	19.6
JUNE	203	280	64.1	70.0	18.5	26.8	103	119	32	126	7.10	9.16	2.01	2.63	1.69	2.36	16.3	24.4
JULY	233	345	66.0	75.0	—	—	102	112	2	51	6.44	7.54	1.67	2.41	1.96	2.11	14.4	19.4
AUGUST	246	305	63.9	71.0	31.2	62.3	102	108	1	29	6.44	7.31	1.96	2.50	2.04	2.66	15.8	20.4
SEPTEMBER	346	423	71.0	87.6	35.2	66.1	117	136	95	254	7.08	8.30	2.54	3.07	2.30	2.56	18.6	23.6
OCTOBER	357	474	75.4	88.2	39.1	45.4	112	132	152	256	5.94	6.54	2.54	2.89	2.24	2.64	17.1	23.8
NOVEMBER	340	438	78.6	95.4	32.4	41.4	126	141	265	401	5.14	6.27	2.80	3.39	2.27	2.61	17.9	27.6
DECEMBER	355	481	97.5	126.6	33.7	45.6	135	156	386	526	7.04	8.86	3.22	4.19	2.26	2.87	19.6	25.6
JANUARY '27	332	372	90.4	100.0	34.0	40.5	123	165	402	530	6.26	7.37	2.80	3.31	2.08	2.50	18.0	23.5
FEBRUARY	289	336	82.1	107.0	32.5	46.3	119	135	222	329	5.22	5.61	2.55	3.01	1.96	2.18	17.2	21.2
MARCH	305	364	80.7	88.6	33.4	38.5	134	150	202	269	5.39	5.83	2.60	3.97	1.94	2.24	18.2	22.2
APRIL	312	406	81.0	91.0	31.0	40.7	132	143	151	254	6.00	6.76	2.48	2.88	1.93	2.46	19.0	25.7
AVERAGE FOR 8 MONTHS [1]	333.2	411.8	82.1	98.1	33.1	45.9	117.6	134.7	168.3	273.9	6.15	7.18	2.45	3.05	2.05	2.43	17.3	23.1

[1] MAY 1926 TO APRIL 1927 INCL. [2] AVERAGE FOR EIGHT MONTHS—SEPTEMBER 1926 TO APRIL 1927 INCL.

TABLE 5. NUMBER OF PATIENTS PER DAY DURING TEST

MONTH		JAN.'26	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.'26	JAN.'27	FEB.	MAR.	APR.'27
PATIENTS PER DAY	AVE.	255	254	265	262	264	240	244	243	219	251	258	234	251	284	277	270
	MAX.	277	268	279	279	276	262	265	259	257	266	280	269	272	297	293	303

TABLE 6. RESULTS OF STUDY OF PEAK LOADS

MONTH	INSTANTANEOUS MAXIMUM FLOW								FIFTEEN MINUTE MAXIMUM FLOW							
	TOTAL CITY WATER				HOT WATER				TOTAL CITY WATER				HOT WATER			
	GALLONS PER HOUR		GAL. PER PATIENT HR.		GALLONS PER HOUR		GAL. PER PATIENT HR.		GALLONS PER HOUR		GAL. PER PATIENT HR.		GALLONS PER HOUR		GAL. PER PATIENT HR.	
	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM	AVERAGE	MAXIMUM
JANUARY 1926	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
FEBRUARY	10200	14000	40.1	55.3	3410	3650	13.4	14.6	7830	11000	30.8	43.5	2760	3450	10.9	13.4
MARCH	9500	12000	35.9	45.3	3560	3700	13.4	14.3	7300	9500	27.5	35.3	2940	3250	11.1	12.2
APRIL	8900	11600	34.0	46.8	3360	3600	12.8	14.9	7080	9700	27.0	39.1	2760	3070	10.5	12.4
MAY	9720	11500	36.8	43.5	3240	3600	12.3	13.6	7650	9000	29.0	33.6	2567	2930	9.8	11.4
JUNE	7830	10700	32.6	45.6	3004	3460	12.5	14.6	5940	8500	25.0	36.1	2350	2750	9.8	11.4
JULY	9110	11800	37.4	47.5	2715	3340	11.1	13.5	6850	8000	28.1	32.9	2310	2610	9.5	10.6
AUGUST	7660	9500	31.6	39.0	3015	3500	12.4	14.6	5720	7400	23.5	30.3	2280	2620	9.4	11.1
SEPTEMBER	7520	10600	34.4	50.3	2985	3250	13.6	15.6	5820	8500	26.6	40.2	2200	2600	10.0	12.7
OCTOBER	7620	8500	30.5	36.4	3240	3600	12.9	15.0	6820	7300	25.2	30.6	2557	2830	10.2	11.8
NOVEMBER	7010	7600	27.2	30.6	3420	3650	13.2	15.1	5810	6600	22.5	27.6	2857	3120	11.0	13.0
DECEMBER '26	7690	8800	32.1	46.6	3580	4000	15.5	21.3	6480	7900	27.6	42.0	3157	3560	13.6	16.9
JANUARY '27	7730	8700	31.0	33.6	3610	4000	14.5	15.7	6570	7600	26.2	29.2	3100	3480	12.4	14.4
FEBRUARY	7350	8800	28.6	32.2	3650	4000	12.9	14.4	6500	7800	22.9	26.9	3090	3450	10.9	12.3
MARCH	8810	9300	30.0	34.6	3550	3750	12.8	13.5	7050	8200	25.4	29.2	3000	3190	10.8	11.5
APRIL	8540	9600	34.5	37.2	3580	3800	13.3	14.6	7150	8400	26.4	30.5	3114	3400	11.5	12.5
AVERAGE FOR 8 MONTHS [1]	7745	9086	30.6	37.7	3455	3770	13.6	15.6	6460	7780	25.4	32.3	2868	3203	11.3	13.4

[1] SEPTEMBER 1926 TO APRIL 1927 INCL.

inaccuracy of meters, since the correction is complicated by the variation in accuracy of meters with respect to rate of flow. The charts of the orifice type of meter showed that the rates of flow varied widely. The accuracy of all meters

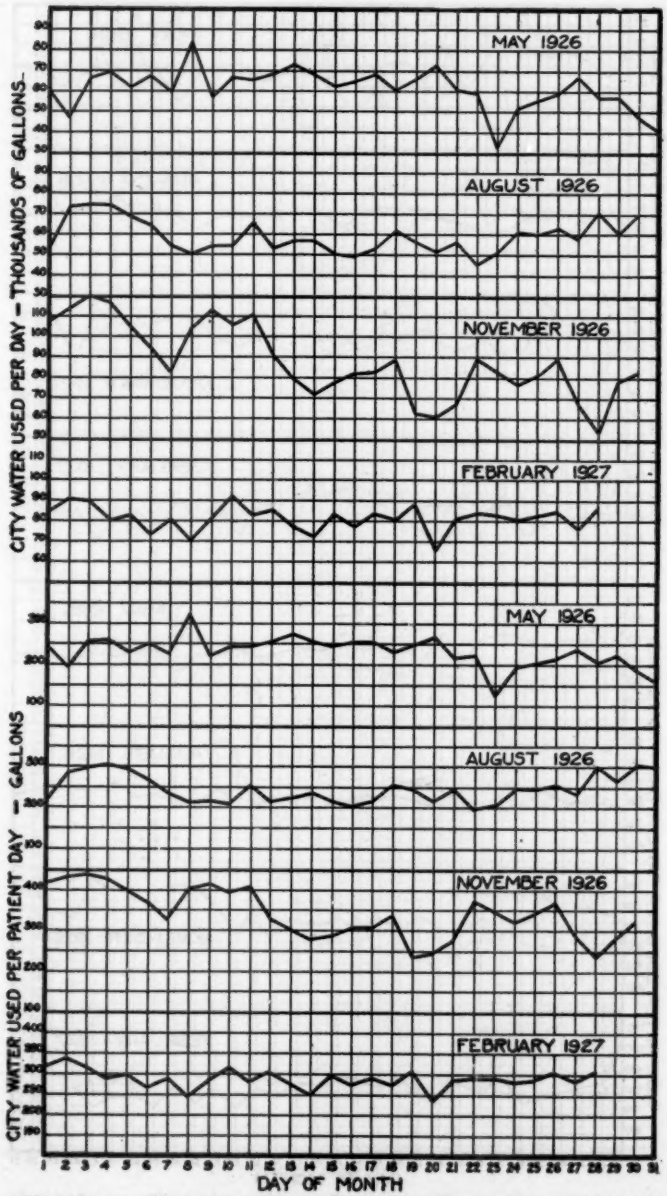


FIG. 7. VARIATION OF CITY WATER REQUIREMENTS FOR TYPICAL MONTHS

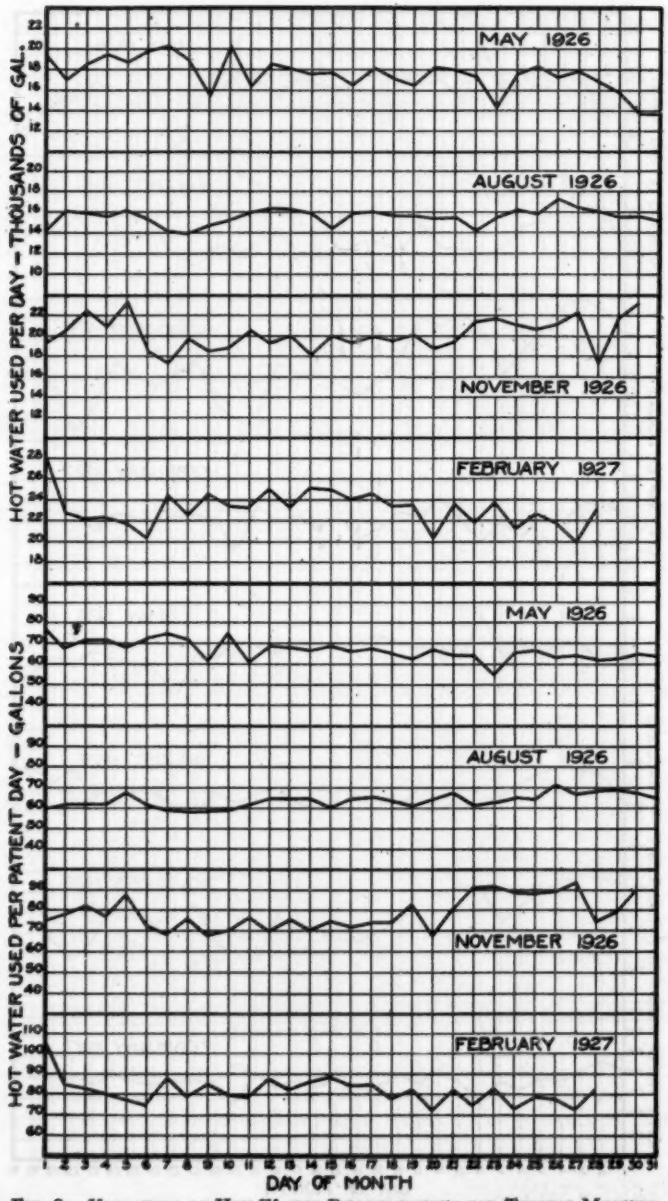


FIG. 8. VARIATION OF HOT WATER REQUIREMENTS FOR TYPICAL MONTHS

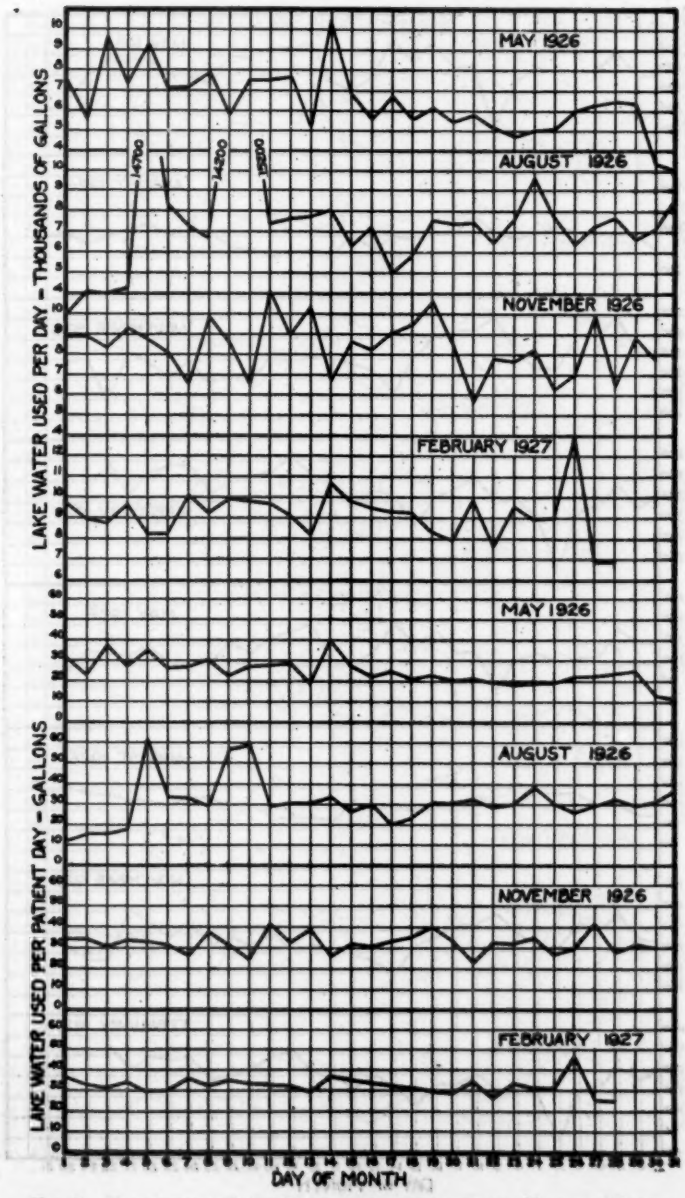


FIG. 9. VARIATION OF LAKE WATER REQUIREMENTS FOR TYPICAL MONTHS

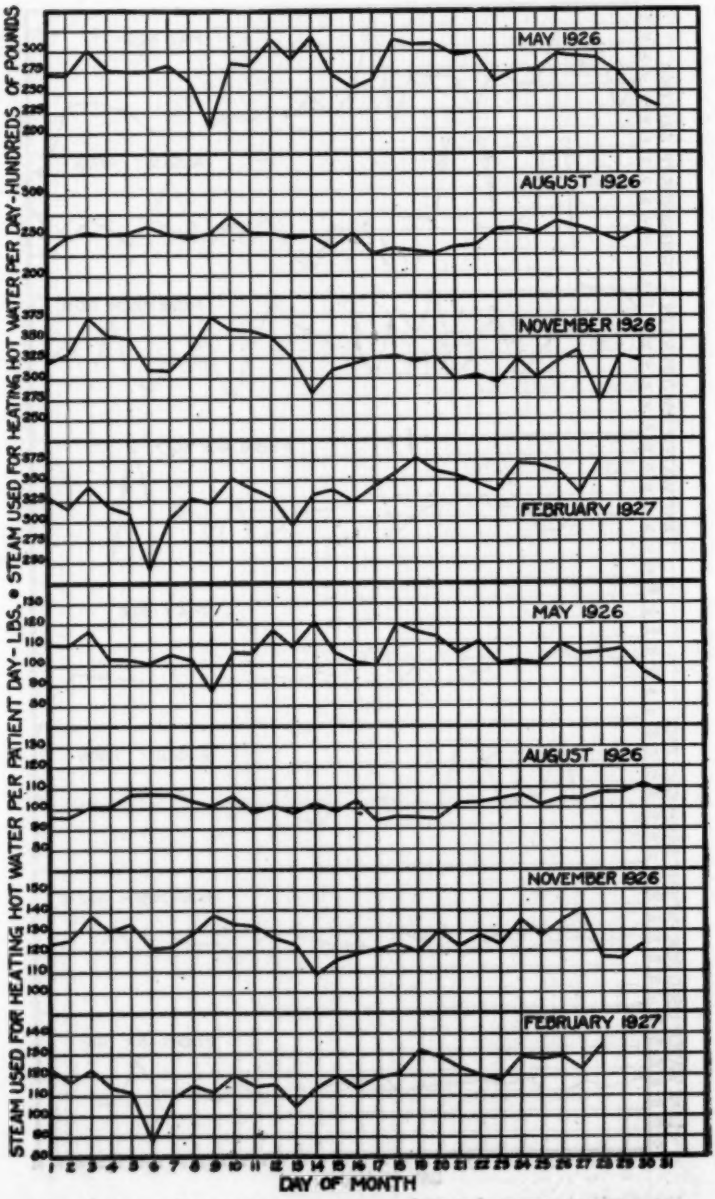

MAY 1926
AUGUST 1926
NOVEMBER 1926
FEBRUARY 1927
MAY 1926
AUGUST 1926
NOVEMBER 1926
FEBRUARY 1927
STEAM USED FOR HEATING HOT WATER PER PATIENT DAY - LBS. • STEAM USED FOR HEATING HOT WATER PER DAY - HUNDREDS OF POUNDS
DAY OF MONTH

FIG. 10. VARIATION OF STEAM USED FOR HEATING HOT WATER IN TYPICAL FOUR-MONTH PERIOD

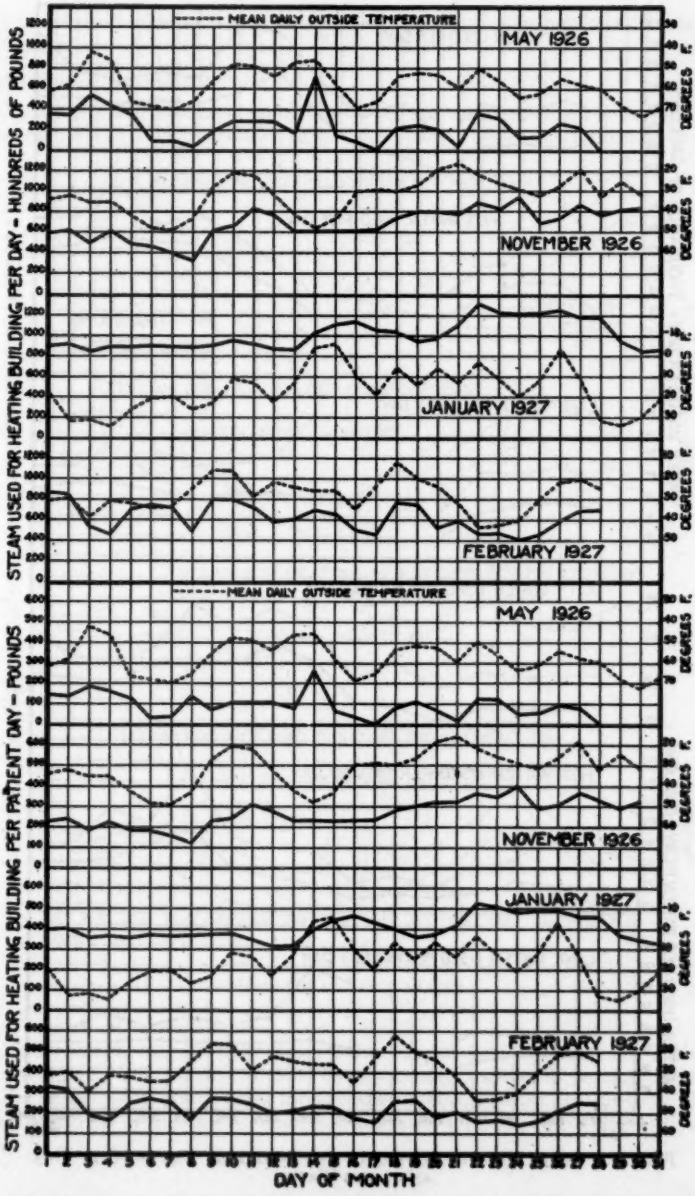


FIG 11. STEAM USED FOR HEATING BUILDING PER DAY—TYPICAL FOUR-MONTH PERIOD

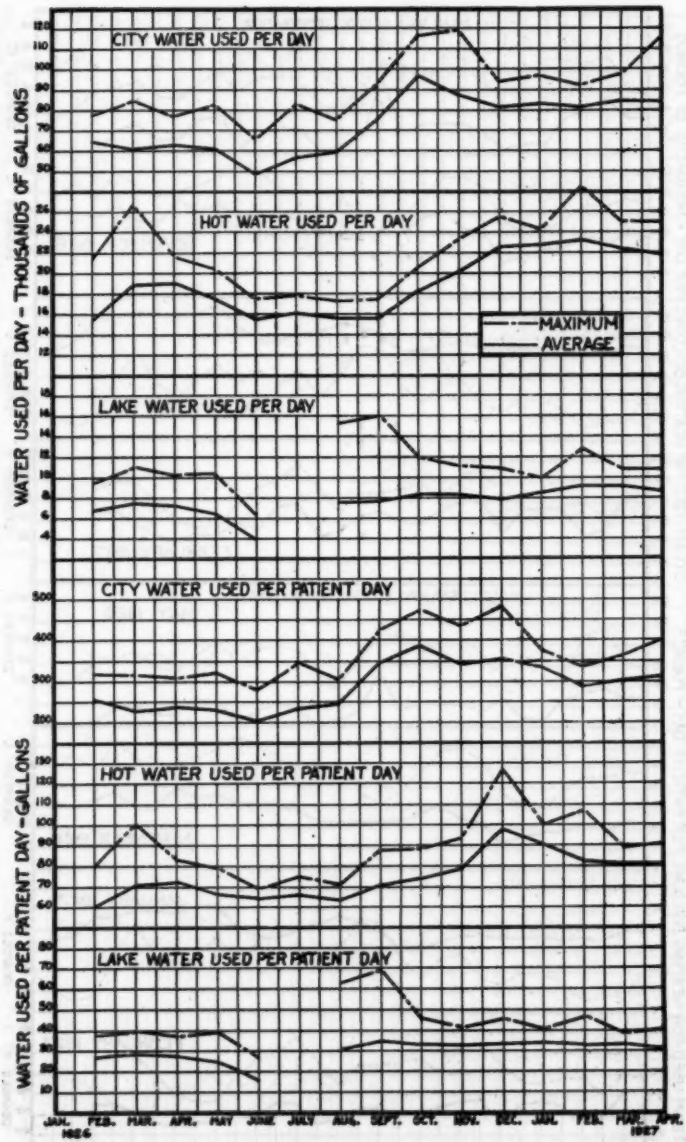

CITY WATER USED PER DAY
HOT WATER USED PER DAY
MAXIMUM
AVERAGE
LAKE WATER USED PER DAY
CITY WATER USED PER PATIENT DAY
HOT WATER USED PER PATIENT DAY
LAKE WATER USED PER PATIENT DAY
WATER USED PER DAY - THOUSANDS OF GALLONS
WATER USED PER PATIENT DAY - GALLONS
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR.
1926
1927

FIG. 12. CHART SHOWING AVERAGE AND MAXIMUM USE OF CITY HOT AND LAKE WATER

was maintained within limits considered reasonable for the purposes of this investigation.

Explanation of Tabulated Results

The average and maximum amount used per day of each item is shown in Table 3 for each of the 16 months of observation. Table 4 shows similar results except

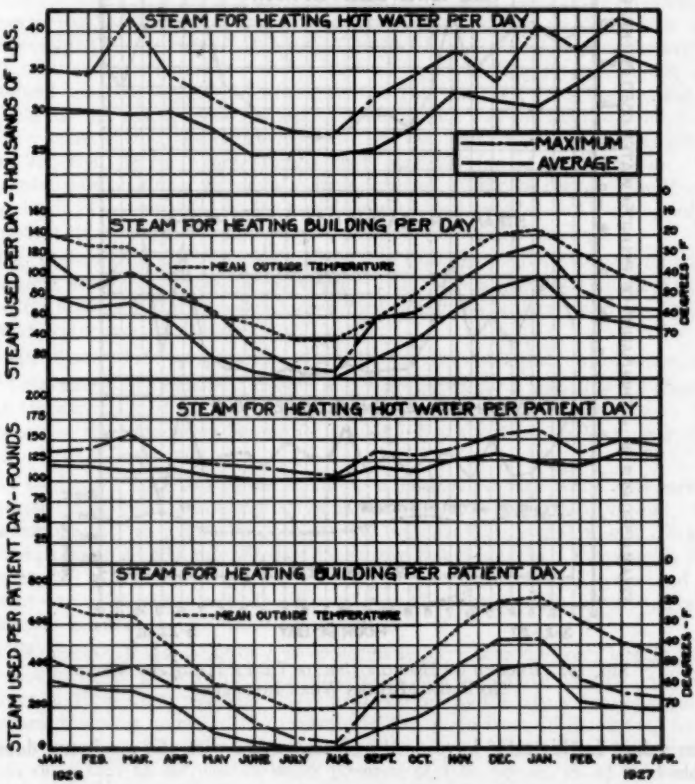

STEAM FOR HEATING HOT WATER PER DAY
MAXIMUM
AVERAGE
STEAM USED PER DAY-THOUSANDS OF LBS.
STEAM FOR HEATING BUILDING PER DAY
MEAN OUTSIDE TEMPERATURE
DEGREES-F
STEAM FOR HEATING HOT WATER PER PATIENT DAY
STEAM USED PER PATIENT DAY- POUNDS
STEAM FOR HEATING BUILDING PER PATIENT DAY
MEAN OUTSIDE TEMPERATURE
DEGREES-F
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR.
1926
1927

FIG. 13. AVERAGE AND MAXIMUM USE OF WATER PER DAY FOR HEATING BUILDING AND HOT WATER

that the values are on the patient-day basis. In the case of averages in Table 4, the averages in Table 3 were divided by the average number of patients per day for the same month, which gives the average amount used per patient-day. The same procedure in the case of maximum amounts would not give the maximum

amount per patient-day. The procedure here was to divide the daily amount of an item used each day, by the number of patients on that day, and pick out the maximum. Table 5 shows the average and maximum number of patients per day, by months, for the period of observation. It should be noted, however, that the maxi-

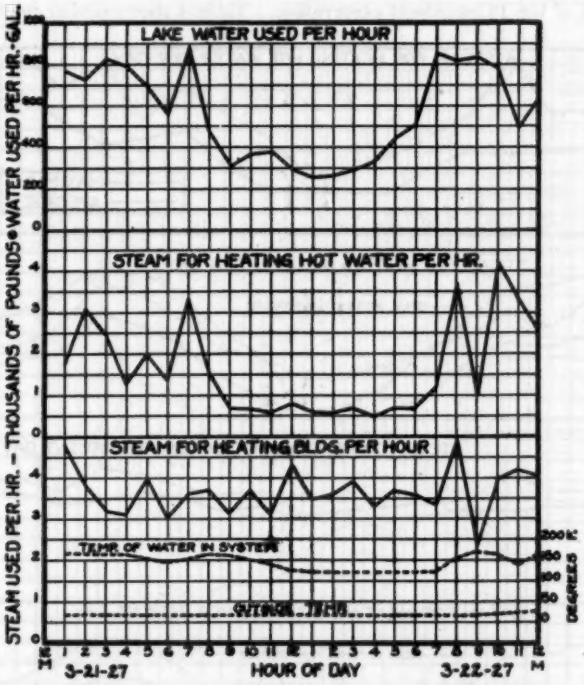

LAKE WATER USED PER HOUR
STEAM FOR HEATING HOT WATER PER HR.
STEAM FOR HEATING BLDG. PER HOUR
TEMP. OF WATER IN SYSTEM
OUTSIDE TEMP.
STEAM USED PER HR. - THOUSANDS OF POUNDS • WATER USED PER HR. - GAL.
DEGREES
3-21-27
HOUR OF DAY
3-22-27

FIG. 14. RECORD OF HOURLY USE OF THREE ITEMS FOR WHICH NO FLOW METERS WERE INSTALLED

mum values in this table have no direct connection with the maximum data of Table 4.

Explanation of Graphical Results

The daily variation of the most important of these items is shown in Figs. 7 to 11, inclusive, on the basis of amount used per day, and per patient-day, for four typical months over a period of a year. Fig. 7 shows this for city water; Fig. 8 for hot water; Fig. 9 for lake water; Fig. 10 for steam used for heating hot water; and Fig. 11 for steam for heating the building.

A graphical presentation of the first five items of Tables 3 and 4 is given in Figs.

12 and 13. The former shows the average and maximum amounts used per day, and per patient-day, of city water, hot water and lake water, and the latter shows the average and maximum amounts used per day and per patient-day, of steam for heating hot water and steam for heating the building.

Explanation of Maximum Demand Data

The recording flow meters gave a means of studying the maximum demands through the 24 hrs. of the day on the city water and hot water. These data are presented in two forms in Table 6. The first half of the table gives the average and maximum instantaneous peaks for each month. The average values were obtained by recording the highest point on the chart for each day during the month, and averaging these values. The maximum was the highest point found on any chart during the entire month. The last half of the table gives similar data for the highest average loads that persisted for at least 15 min. The instantaneous peak may, or may not, have occurred within the period of the 15-min. peak load. In some instances the top of the peak load went beyond the range of the recording chart, and it was necessary to estimate the trace of the load.

Fig. 14 shows for one day, on an hourly basis, the amounts of items used for which recording flow meters were not provided. This figure shows the amount of steam used for heating hot water, steam used for heating the building, and the amount of lake water used each hour.

Figs. 15 and 16 show typical flow charts for the city water and the hot water used.

The averages of items in Tables 3 and 4 are given for a period of 12 months, with the exception of the averages of city water, hot water and lake water. The averages of the latter were figured for a period of 8 months from September, 1926 to April, 1927, inclusive.

At the beginning of this period there was a distinct increase in the consumption of water which persisted during the remainder of the period of observation. The average quantity of city water used per day previous to this time was 59,000 gal., as compared to 84,500 gal. per day during the last 8 months. Previous to September, 233 gal. were used per patient-day, and after this, 333 gal. were used per patient-day. On either basis, the increase was 43 per cent. Fig. 12 shows graphically this increase in city water consumption.

This increase in the use of city water seems to have been due very largely to an increase in water pressure in the main serving the university district. On September 10, 1926, a new reservoir was put into service by the city water department. The new reservoir increased the pressure in this main from 76 lb. per sq. in. to 83 lb. per sq. in. The water department of the city of Madison has kept records which show that an increase in water pressure of 1 lb. per sq. in. at the central pumping plant results in a 2 per cent increase in water consumption for the city. The increase in pressure of 7 lb. per sq. in. would then account for 14 per cent increase in consumption, if the hospital were an average section of the city load. However, it is likely that in such an institution an increase in pressure increases the water consumption more than for the city in general. The city load is determined largely by the consumption in private homes which have but few outlets and no uses of continuously running water, whereas the hospital has a multiplicity of outlets, averaging 2.5 per patient; and has several pieces of equipment, such as

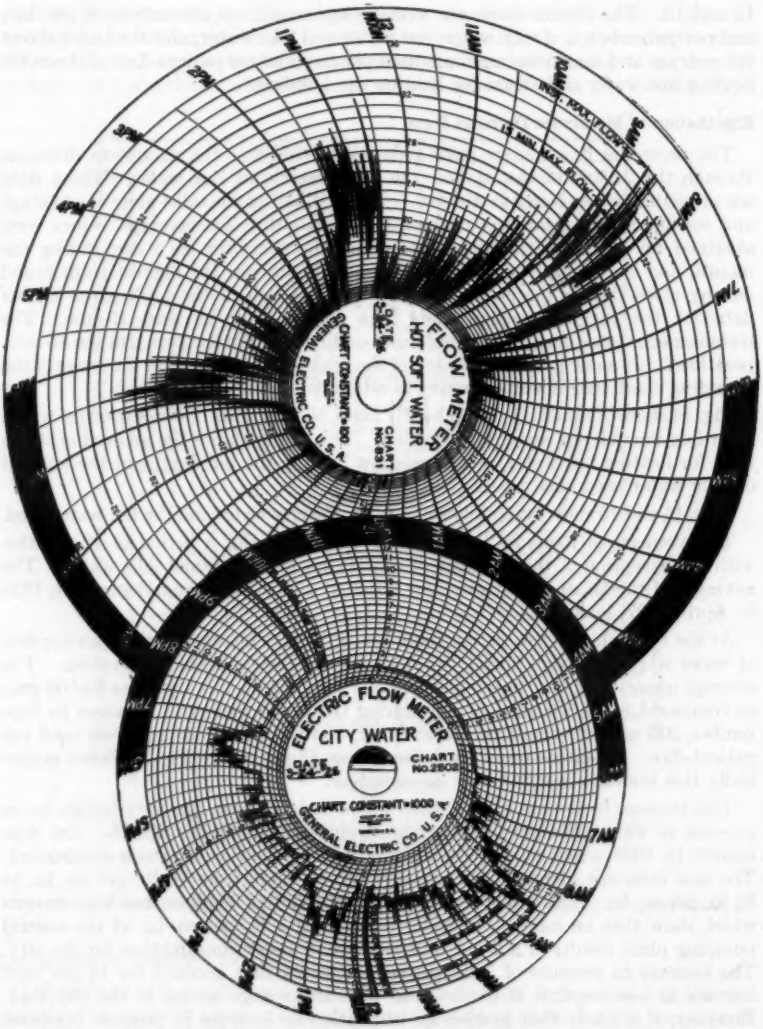


FIG. 15. RECORDING CHART RECORDS OF WATER USED

a refrigeration machine, x-ray developing apparatus, drinking fountains and water sterilizing equipment that use water continuously.

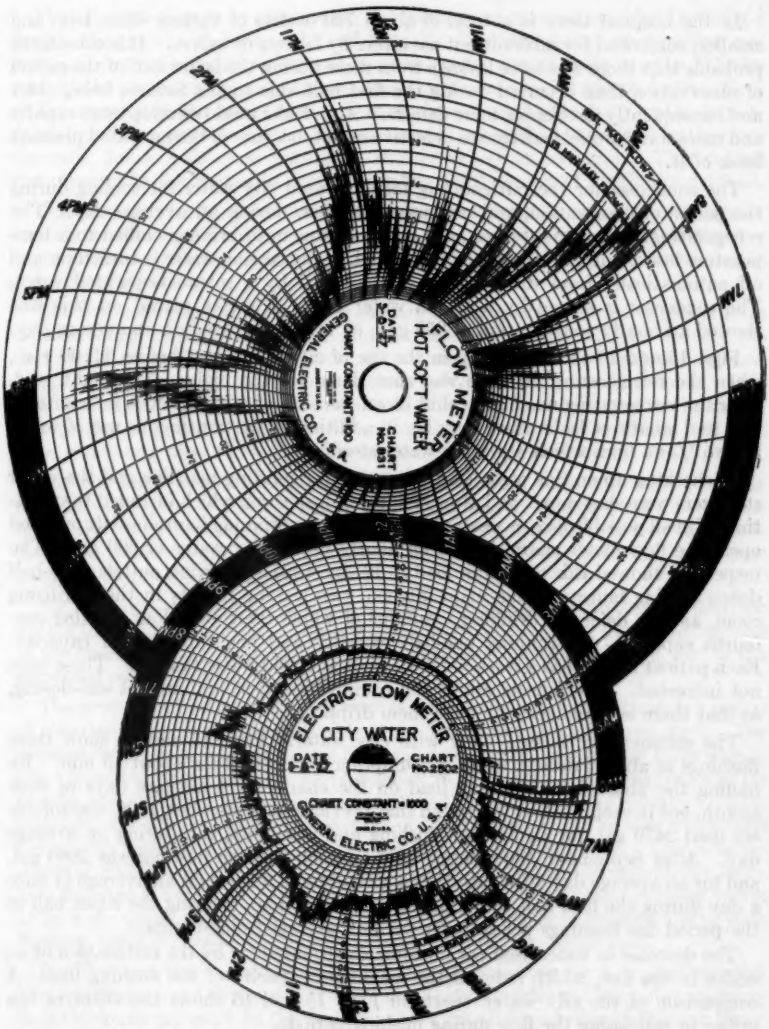


FIG. 16. TYPICAL FLOW CHART FOR CITY AND HOT WATER

The hospital is equipped with 24 drinking fountains of the self-closing type. The self-closing feature has been made inoperative on several and, at times, others have been propped open.

In the hospital there is a total of about 700 outlets of various sizes, 1 in. and smaller, controlled for intermittent use either by faucets or valves. It is considered probable that there was more leakage from these during the latter half of the period of observation than occurred during the first half, due to the fixtures being older and consequently developing more defects. Also, leaks would develop more rapidly and more water would leak from a defective outlet, because of the increased pressure back of it.

The condenser for the refrigerating machine used city water for cooling during the period of observation, and was used 13.2 hrs. during an average day. The refrigerating machine is started at 7 A.M. and runs until brine is chilled to a temperature low enough to handle the night load. The cooling water is turned on and off automatically from the machine switch-board by a solenoid-operated valve. The condenser is served by a $^1/_2$ in. water line. A meter placed on this line showed an hourly consumption of 850 gal., or 11,220 gal. used on an average day.

Figs. 15 and 16 show the drop in the use of city water just before 11:00 P.M., when the refrigerating machine was shut down for the night. The night load, after the refrigerating machine is shut down, consists of miscellaneous intermittent uses and whatever leaks there may be, in addition to the continuous use of water in two $^1/_2$-in. lines which serve the water sterilizers.

In checking up on this night load, after the refrigerating machine and the water sterilizers were shut down, and after making an inspection which included the shutting off of all possible uses or wastes of water, such as drinking fountains left propped open, the flow meter chart showed an hourly use of city water of 600 gal. The inspection showed this minimum load to be due to the following outlets: one-half dozen leaking faucets in the main kitchen, two leaking faucets in the sterilizing room, and six defective drinking fountains of which there were four running one-fourth capacity, one running one-half capacity and one running full capacity. Each patient's room has a wash bowl with hot and cold water faucets. These were not inspected. The faucets are of the compression type and are not self-closing, so that there is a tendency to leave them dripping.

The softeners are flushed daily with city water. Figs. 15 and 16 show these flushings as abrupt rises in water consumption that persist for about 15 min. By finding the area of the flushing load on the charts for 4 average days of each month, one in each week, it was found that previous to September, 1926, the softeners used 2470 gal. for an average flushing and used 4860 gal. during an average day. After September, the amount used for each average flushing was 2040 gal. and for an average day 3610 gal. Each softener was flushed on an average of once a day during the first half of the period of observation. During the latter half of the period the flushings per softener per day averaged nine-tenths.

The decrease in water used per flushing is accounted for by the installation of an orifice in the line, which reduced the maximum capacity of the flushing line. A comparison of the city water charts in Figs. 15 and 16 shows the effect of the orifice in restricting the flow during flushing periods.

The hot water system accounts for about 4000 gal. of this 25,500 gal. increase in the use of city water There was a 24 per cent increase in the use of hot water during the last 8 months as compared with the amount used during the first half of the period of observation.

The effect of change in pressure on the water consumption can also be noticed during the months of June, July and August. The city water consumption per day, and per patient-day, decreased to some extent during these months. There seems to be no reason for this decrease from the use standpoint except for the effect of the decrease in hot water used. During these 3 months the city water department found it necessary to limit the pumpage because of a shortage of water from the wells, due to a delay in getting an additional well in operation. This caused the pressure in the mains to drop during the daily periods of maximum demand.

The increase in city water pressure then is considered to account very largely for the increase in city water consumption. No changes were made in treatments or in kitchen operations requiring the increased use of water. No laundering is done in this building.

The hot water consumption during the last 8 months of the period of observation on an average day was 20,900 gal. and per patient-day was 82 gal. During the first half of the period of observation, the consumption was 16,840 gal. per day and 66 gal. per patient-day. This is an increase of 24 per cent on either basis. This increased use is considered to be due to the increased pressure on the city mains and to the dropping of the temperature of the hot water from 180 to 170 deg. fahr. which was done to reduce corrosion in the storage tank.

The hot water system, since it is used intermittently from outlets, is probably more nearly typical of the average city load than the city water system of the hospital. By this reasoning 14 per cent of the 24 per cent increase in hot water consumption would be due to the increase in pressure and the remaining 10 per cent would be due to the drop in temperature.

Fig. 12 shows this increase in water consumption and also shows a slight decrease during the summer months. This is considered to be due to the decreased pressure in the mains during periods of maximum demand, as mentioned before, and to the decreased use of hot water in the summer season.

The averages of lake water used were taken for the last 8 months of the period of observation so as to be comparable to the city water and hot water used. The average daily use of lake water was 8430 gal. and on the patient-day basis was 33 gal. Sand interfered with the by-pass meter in June; the meter was removed for testing and overhauling in July; hence, only the months from February to May, inclusive, are left for finding the average of the first period. The lake water used during this time was 6992 gal. per day and 27 gal. per patient-day. This is an increase of 20.7 per cent on the daily basis and of 24 per cent on the patient-day basis. This increase is unaccounted for, unless by the increased leakage of flushing valves or by a change in adjustment that caused additional water to be used during each flushing. Fig. 12 shows graphically this increase in lake water used.

Fig. 9 shows the variations in lake water consumption for 4 typical months. The registration was obviously incorrect on the last two days of May, due probably to interference by sand in the meters. This condition continued through June. The registration of the first 4 days of August likewise appears low. On the 5th, 9th and 10th of this month, the registration was double that of an average day. This abnormal use of lake water on these days was due to the operating engineer having circulated lake water through the heating system in an attempt

TABLE 7. COMPARISON OF MAXIMUM RATES TO AVERAGE RATES OF CONSUMPTION

Ratio	On per Day Basis									On per Patient-Day Basis								
	City water	Hot water	Lake water	Steam for hot water	Steam for building	Ice made	Elec. for lights	Elec. for power	City gas	City water	Hot water	Lake water	Steam for hot water	Steam for building	Ice made	Elec. for lights	Elec. for power	City gas
Average Maximum Daily Consumption to Average Daily Consumption	1.22	1.15	1.4	1.16	1.59	1.05	1.2	1.16	1.34	1.23	1.20	1.39	1.15	1.63	1.17	1.25	1.19	1.34
Maximum Daily Consumption to Average Daily Consumption	1.41	1.36	1.91	1.40	3.06	1.28	1.45	1.32	1.68	1.44	1.54	2.09	1.39	3.15	1.49	1.71	1.4	1.6
Average 15 Minute Peak Consumption to Average Daily Consumption	1.84	3.31								1.83	3.3							
Average Maximum 15 Minute Peak Consumption to Average Daily Consumption	2.21	3.67								2.33	3.92							
Maximum 15 Minute Peak Consumption to Average Daily Consumption	2.42	4.1								3.03	5.5							
Average Instantaneous Peak Consumption to Average Daily Consumption	2.2	3.96								2.22	3.97							
Average Maximum Instantaneous Peak Consumption to Average Daily Consumption	2.56	4.33								2.72	4.55							
Maximum Instantaneous Peak Consumption to Average Daily Consumption	3.01	4.6								3.62	6.21							

NOTE.—The values in this table are figured for the same period of months as are the averages of Tables 3, 4 and 6.

to cool the building. In figuring the average no correction was made since these abnormally high and low registrations offset each other.

The steam termed steam for heating hot water includes in addition to that used for hot water, steam that is used in sterilizers and for cooking. The average amount used per day for the 12 months' period from May, 1926 to April, 1927, inclusive, was 29,795 lb. and per patient was 118 lb.

The steam used for heating the hot water only was calculated for the 8 months for which the average daily consumption of hot water was given. Account was taken of the heat utilized in heating the water by the condensate from the sterilizers. The equation used was $20{,}896 \times 8.34(170-50) = 1006(31{,}874 - X) + 130\,X$, where X is the pounds of steam used for sterilizing and cooking. The amount used for sterilizing and cooking was 40 per cent of the total and for heating hot water was 60 per cent. This calculation does not allow for the radiation losses in circulating the hot water. Fig. 14 shows a night load of about 600 lb. of steam used in heating hot water and sterilizing. It is considered that this amount was used in two water sterilizers, and to replace radiation losses. Fig. 14 shows a peak in steam used for hot water in the hour from 7 to 8 A.M. and from 9 to 10 A.M., with a valley from 8 to 9 A.M. Figs. 15 and 16 show a period of maximum demand from 8 to 9 A.M. This difference in the time of maximum demand of the two items probably is due to the hold-over capacity of the large hot water storage tank.

The averages of steam used for heating the building are given in Tables 3 and 4 for a period of 12 months. For the 9 months considered as the heating season, leaving out June, July and August, the average daily use of steam was 51,615 lb. The consumption per patient-day was 220 lb. Fig. 13 shows that the average steam consumption per patient-day follows the trend in outside temperature as closely as does the steam consumption per day.

At the University of Wisconsin, the heating season is figured as 260 days from September 15 to June 1, inclusive. For the hospital building, in the year 1926–1927, the steam used was 421 lb. per sq. ft. of hot water radiation per heating season. For the entire University, the steam used per square foot of steam radiation per heating season was 810 lb.

Conclusions

The total water used per patient-day was 366 gal. This is the sum of the city water and lake water averages on the patient-day basis during the last 8 months of the period of observation. During this time the condenser on the refrigerating machine used 11,220 gal. on an average day, or 44 gal. per patient-day. The flushing of softeners account for 3610 gal. on an average day, or 14 gal. per patient-day. Without the mechanical refrigeration plant and water softeners, the total water consumption would have been 308 gal. per patient day.

The hot water used per patient-day was 82 gal. This is 22.4 per cent of the total water used, or 26.6 per cent of the total water used exclusive of water for softener flushing and for cooling in the refrigeration plant. It should be noted that the above figures are for a hospital without a laundry.

The per-capita water consumption per day of the city of Madison is 102 gal. A comparable unit for the hospital would be the per-occupant-per-day consumption.

During the entire period of observation the number of occupants other than patients remained practically constant. There were about 55 full-time and part-time doctors and interns, 120 nurses and 260 employees. The total estimated to be on duty during the day time was 360. The use of this number was considered to give the fairest basis of calculating the consumption per-occupant-per-day. Exclusive of the water used for softener flushing, and cooling in the refrigeration plant, this gives a per-occupant-per-day consumption of 127 gal.

Table 7 gives a comparison of maximum rates to average rates of consumption. As an illustration, this table shows that on the per patient-day basis for city water there was a peak period of consumption 2.33 times the average rate of consumption lasting for at least 15 min. on the average day. For hot water this ratio is shown to be 3.92. This comparison shows that the hot water demand is more fluctuating than the total water demand. In determining the sizes of heaters, softeners, pipe lines and other pieces of equipment, it is important to know the maximum demands as well as the average demands that must be met. For instance, a softener installed on the hot water system should not only be able to handle the daily load of 82 gal. per patient-day, but must be able to handle a load 3.9 times this amount for a period of at least 15 min. If it is not designed or chosen to meet the load during times of maximum demand, the water will not be entirely softened, and in some cases damage to the filter bed may occur. Likewise, the heater and the storage tank for the hot water system must be chosen with respect to the maximum demands for hot water. With a given ratio of maximum demand to average demand, either the heater must have sufficient capacity to handle this entire maximum load, or a storage tank must be provided of such a size that the maximum demands above the amount that can be handled by the heater will be drawn from the storage tank, with not more than the allowable drop in temperature.

DISCUSSION

H. H. ANGUS: This paper gives a lot of very interesting information in regard to the fluctuation of the load on a hospital. Table 4 puts this on the basis where it can be compared with other hospitals. In connection with the electric work on Table 4, the word kilowatt is used. Should it not be kilowatt hours?

PROFESSOR LARSON: The heading should be kilowatt hours.

MR. ANGUS: I have data on a 700-bed hospital and a 300-bed hospital and I just wanted to make a comparison. On the 700-bed hospital, there was used 340 U. S. gallons per patient-day and on the smaller one 322. On these two hospitals the laundry requirements are close to 40 gallons per day so that the figures to compare with Table 4 would be around 300 gallons per patient day, which is very considerably below the figures for the hospital described in the paper.

The ice used for packs for the two hospitals to which I refer is about 5 lb. per patient-day, which corresponds very closely to the one described. The average electric load per patient-day is around $5^1/_2$ kilowatt hours for both these hospitals and the peak load for 15 min. about 0.28 kilowatts. The peak load is only about 18 or 20 per cent of the total electrical load in a hospital.

No. 803

AIR LEAKAGE STUDIES ON METAL WINDOWS IN A MODERN OFFICE BUILDING

By F. C. Houghten and M. E. O'Connell

SYNOPSIS

In this report, the Research Laboratory of the American Society of Heating and Ventilating Engineers presents information concerning the leakage of air through metal windows in a modern office building, and the effectiveness of weatherstripping in its reduction. The reasons for the investigation, method of attack, instruments used and the magnitude and significance of the results are discussed.

A STUDY of air infiltration through metal windows in a modern office building and the effect of weatherstripping in reducing this leakage was made possible by cooperation between the Research Laboratory of the American Society of Heating and Ventilating Engineers and other organizations. The Southwestern Bell Telephone Co., through its architects, Mauran, Russell, and Crowell, and associate architect, I. R. Timlin, made available space and other facilities for the study in its new building in St. Louis. The Athey Co., The Campbell Metal Window Corp., The Chamberlain Metal Weatherstrip Co., and The Monarch Metal Products Co., each equipped one window with its weatherstripping, or leakage retarding improvement, and furnished other equipment necessary for the tests. Arrangements for the investigation were completed* by S. R. Lewis, chairman of the Committee on Research of the Society, and representatives of the other organizations. The investigation was made by the staff of the Laboratory during May and June.

Type of Building Studied

The Southwestern Bell Telephone Building in St. Louis, Fig. 1, is a modern skyscraper of the setback type, partly occupied by the telephone company for its exchange and office requirements. The other space in the building is leased for

* Late in April, 1927.

Presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, New York, N. Y., January, 1928.

office purposes. The building is 32 stories high and contains 514,380 sq. ft. of floor space.

Windows having a northern exposure in the northwest corner of the eleventh floor were chosen for test. These windows are indicated by x-x in Fig. 1, while

FIG. 3. SOUTHWESTERN BELL TELEPHONE BUILDING, ST. LOUIS, MO.

Fig. 2 shows a plan of the eleventh floor. Windows 1, 2, 3, 4 and 5 were tested. Window 6 was used for collecting wind pressure data and for other observations.

Probable Value of Results of Study

The investigation was of particular interest to engineers, architects, and building owners.

1. It gave an opportunity to study infiltration through metal windows on which little or no data have been available.

2. It offered information on the average effect of various types of leakage retarding devices in reducing infiltration through such windows.

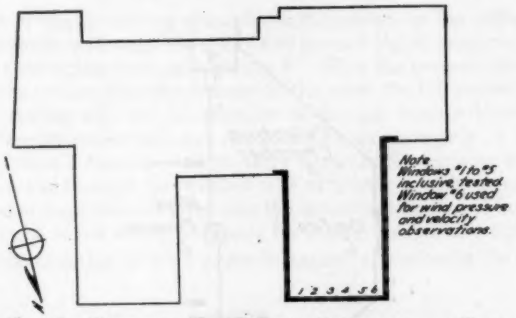


FIG. 2. ELEVENTH FLOOR PLAN, SOUTHWESTERN BELL TELEPHONE BUILDING

3. It offered an opportunity to demonstrate the feasibility of making infiltration tests on windows in an actual building.

4. It was hoped that the findings would give an indication of the reliability of results on air leakage through windows collected under laboratory conditions where an artificial wind pressure is created by fans.

Proposed Apparatus

The investigation offered difficulties as well as opportunities not encountered in the Laboratory. Originally, it was planned to measure the air leakage through the windows by the orifice method in a manner similar to that developed and used by the Laboratory in its infiltration studies in Pittsburgh. Fig. 3 is the apparatus developed and used by the Laboratory for determining leakage through windows. A static pressure equivalent to any desired wind velocity is maintained in the pressure chamber *A*, and the air leaking through the window or other construction is collected in chamber *D* and measured as it passes out through the orifice *E*.

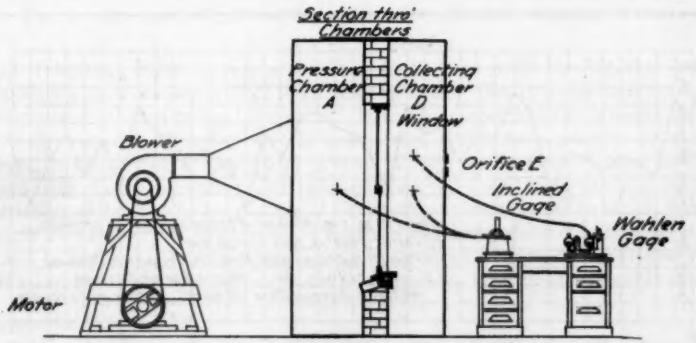


FIG. 3. LABORATORY APPARATUS FOR STUDYING AIR LEAKAGE THROUGH BUILDING CONSTRUCTION

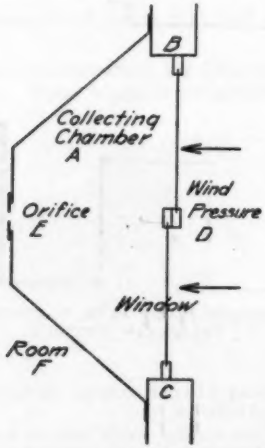


FIG. 4. ORIFICE METHOD PROPOSED FOR MEASURING INFILTRATION THROUGH WINDOWS

Fig. 4 is a modification of the Laboratory apparatus which it was thought could be used for determining leakage through actual windows. The collecting chamber *A* is clamped against the wall *BC* containing the window. Air leaking through the window due to a wind pressure on the outside is collected in chamber *A* and measured as it passes out through orifice *E*.

There are two fundamental difficulties with this method of procedure. *First*,

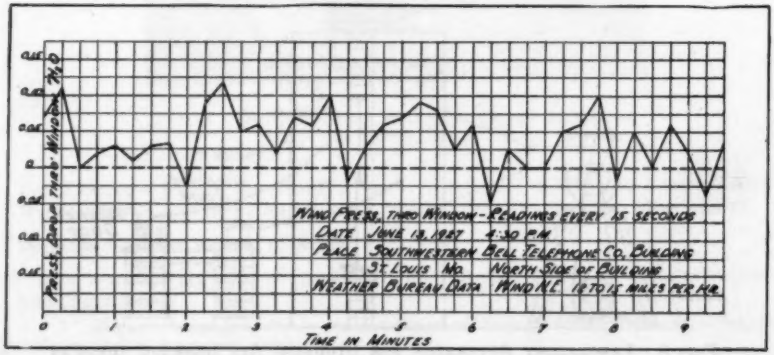

Press. Drop thro' Window in "H2O
Time in Minutes
Wind Press. thro Window - Readings every 15 seconds
Date June 19, 1917 4:30 PM
Place Southwestern Bell Telephone Co. Building
St. Louis Mo. North Side of Building
Weather Bureau Data Wind N.E. 12 to 15 miles per hr.

FIG. 5. VARIATION IN WIND PRESSURE

measurement of the air leaving the collecting chamber by the orifice method requires a pressure drop through the orifice and hence a higher pressure in the collecting chamber than in the surrounding room *F*. Since the pressure in the collecting chamber will be greater than the pressure in the room, the full pressure of the wind against the window will not be effective in causing leakage through it. The observed infiltration under such test conditions would necessarily be less than normally taking place. *Second*, wind pressure is extremely variable and hence the rate of infiltration through the window will vary over a wide range. Since the orifice method of measurement gives only the instantaneous rate of flow at the time of observation, it is not easily adaptable for measuring variable flow.

Fig. 5 shows variation in wind pressure against a window in the Southwestern

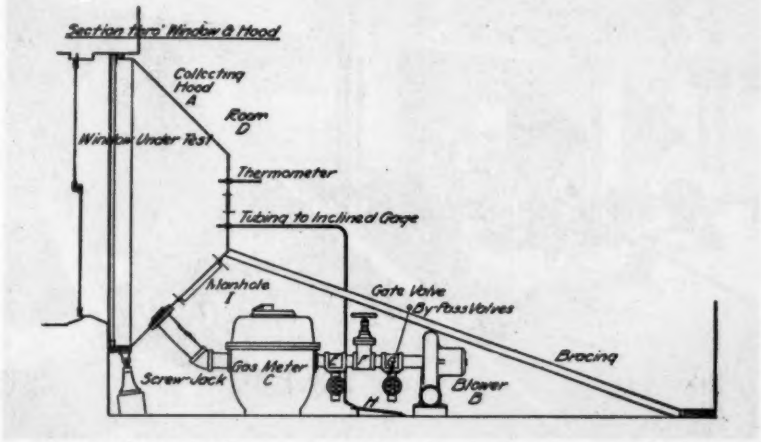


FIG. 6. APPARATUS USED FOR MEASURING INFILTRATION THROUGH WINDOWS

Bell Telephone Building over a period of 10 minutes while the Weather Bureau reported a northeast wind of 12 to 15 miles an hour. Observations were made and the pressure plotted every 15 seconds. It will be noted that the pressure was extremely variable, changing several times from a maximum positive to a small negative value over a very short period. If an orifice method were used for measuring the leakage, the orifice pressure observed would show the same cycles of variation, although the magnitude of variation would probably be much less. It would be necessary to take frequent readings and integrate the area under such a curve in order to determine the quantity of air leaking through the window over a period of time. Obviously this would be impossible without considerable error.

Apparatus Used

Because of these difficulties the method shown in Fig. 6 was finally adopted and used throughout the tests. The collecting hood *A* was clamped to the wall around

the window under test. Air was exhausted from the collecting chamber by means of the blower *B* through the gas meter *C* so as to maintain zero pressure difference between the collecting chamber *A* and the room *D*. This insured the same leakage through the window at any wind velocity as would take place if the collecting chamber was not clamped to it. In other words, it insured normal leakage through the window.

A calibrated gas meter was used for measuring the air taken from the collecting chamber. The exhaust fan used had a capacity in excess of the estimated requirement for exhausting all of the infiltering air through the meter. Valves *E*, *F*, and *G* made it possible to control the flow so as to maintain a constant pressure in the collecting chamber equal to that in the surrounding room, as indicated by

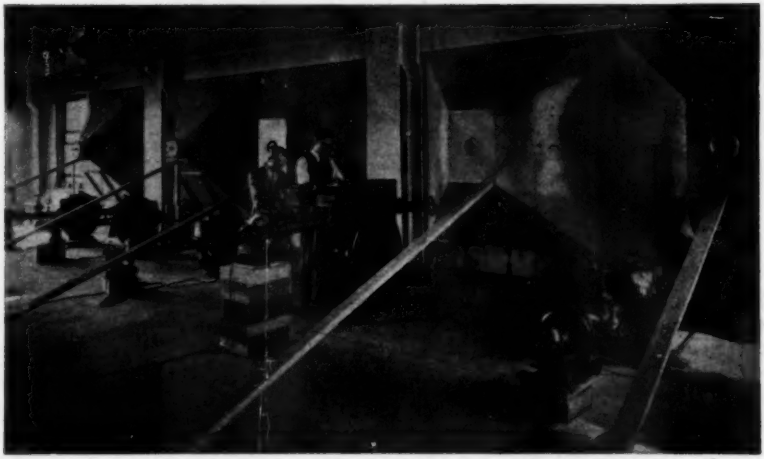


FIG. 7. TEST SET-UP FOR MEASURING INFILTRATION THROUGH WINDOWS IN SOUTHWESTERN BELL TELEPHONE BUILDING

a sensitive inclined pressure gage *H*. Meters having a capacity of 5000 cu. ft. per hour were used for testing the weatherstripped windows. A 10,000 cu. ft. meter was used for testing the non-weatherstripped window. Standard 4-in. pipe was used for the duct between the collecting chamber and meter, and 3-in. pipe between the meter and blower. A 3-in. gate valve was used for main control, and 2-in. valves for bypass control.

The five meters were lent for the tests by the Pittsburgh Equitable Meter Co., and were calibrated at the factory before shipment. To insure that after applying the calibration correction they all read alike after shipment, they were compared at the scene of the tests before they were installed. All five meters were connected in series with one of the exhaust blowers, and air was drawn through them at various rates. After taking into consideration the difference in pressure of the air passing through the different meters due to the pressure drop through the series, and after

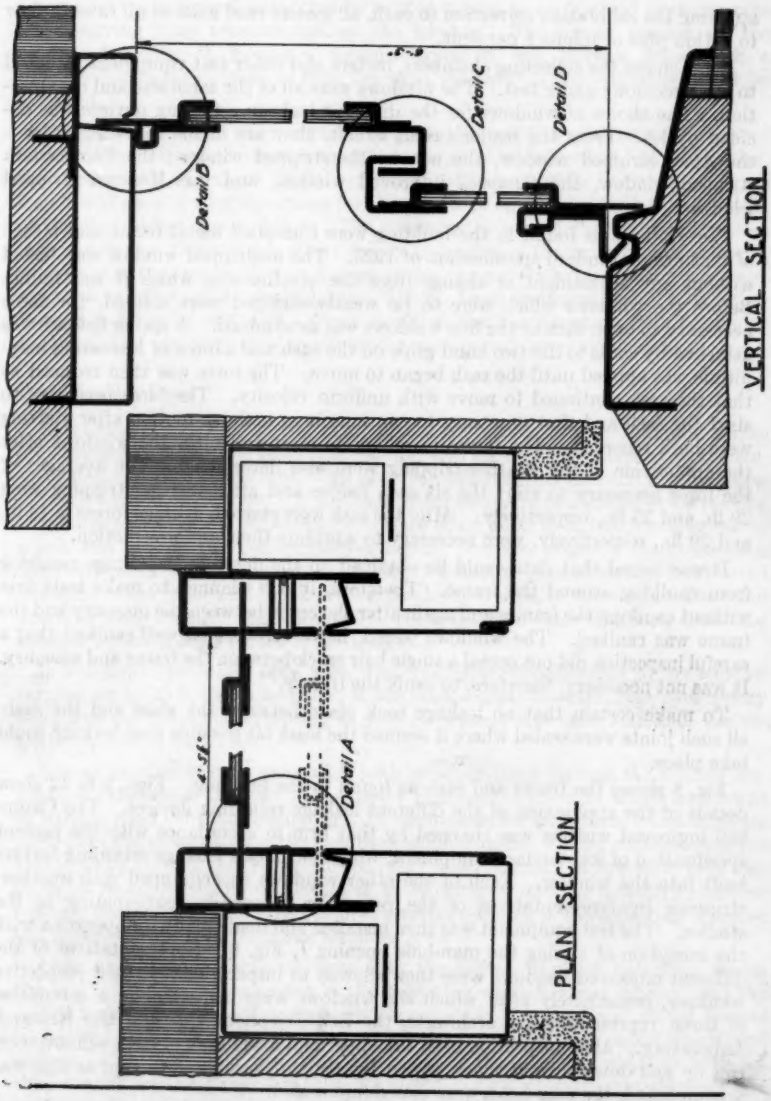


FIG 8. CAMPBELL METAL WINDOW WITHOUT WEATHERSTRIPPING

applying the calibration correction to each, all meters read alike at all rates of flow to within plus or minus 1 per cent.

Fig. 7 shows the collecting chambers, meters and other test equipment attached to the 5 windows under test. The windows were all of the same size and construction. The choice of windows for the different leakage retarding devices was decided by lot. From the reader's right to left, they are in the following order—the *Athey* stripped window, the non-weatherstripped window, the *Chamberlain* stripped window, the *Campbell* improved window, and the *Monarch* stripped window.

The windows as found in the building were Campbell metal frame and a sash of that firm's standard specification of 1925. The unstripped window was tested without any adjustment or change from the condition in which it was found. Before the windows which were to be weatherstripped were altered, the force necessary to open each of the five windows was determined. A spring balance was attached by cords to the two hand grips on the sash and a force of increasing magnitude was applied until the sash began to move. The force was then reduced so that the sash continued to move with uniform velocity. The force necessary to start the sash and that necessary to continue it in uniform motion after starting were both recorded. The forces necessary to start and open the windows after the application of the weatherstripping were also determined. The averages of the force necessary to start the six sash before and after weatherstripping were 29 lb. and 35 lb., respectively. After the sash were started, average forces of 14 lb. and 20 lb., respectively, were necessary to continue their uniform motion.

It was hoped that data could be obtained on the decrease in leakage resulting from caulking around the frame. Therefore, it was planned to make tests first without caulking the frames and again after the crack between the masonry and the frame was caulked. The windows tested, however, were so well caulked that a careful inspection did not reveal a single hair crack between the frame and masonry. It was not necessary, therefore, to caulk the frames.

To make certain that no leakage took place between the glass and the sash, all such joints were sealed where it seemed the least bit possible that leakage could take place.

Fig. 8 shows the frame and sash as found in the building. Figs. 9 to 12 show details of the application of the different leakage retarding devices. The Campbell improved window was changed by that firm in accordance with the present specification of its standard equipment, which includes a leakage retarding feature built into the window. Each of the other windows was equipped with weatherstripping by representatives of the respective companies participating in the studies. The test equipment was then installed and made ready for operation with the exception of closing the man-hole opening *I*, Fig. 6. Representatives of the different improved windows were then allowed to inspect, finally, their respective windows, immediately after which the windows were inspected by a committee of three, representing the architects, the Bell Telephone Co. and the Research Laboratory. After inspection both the upper and lower sash of each window were run up and down several times, closed tightly and locked. As soon as this was accomplished, the man-holes were closed and sealed.

The sixth window left, Fig. 2, was fitted with a tube leading outside, flush with

the window surface, and connected by rubber tubing to an inclined pressure gage for observing wind pressure against the window. The corner window at the reader's left, Fig. 2, having a western exposure, was likewise fitted with a tube leading to the outside, so that the wind pressure on this exposure could be observed.

A Tycos electric cup anemometer was placed on top of a pent-house on the roof of the Majestic Hotel, across the street from the windows under test. At that point, the anemometer was about 100 ft. in front of, and about 20 ft. below the windows tested, and clear of all obstructions for about a block on all sides, with the exception of the Bell Telephone Building. The anemometer was of the electrical contact indicator type. Observation of the change in reading of the indicating instrument, which was in the test room, over a given period, gave the wind travel and the average wind velocity could be calculated. The St. Louis station of the U. S. Weather Bureau is 4 blocks east and 1 block north of the Southwestern Bell Telephone Building, and meteorological readings for any period were available.

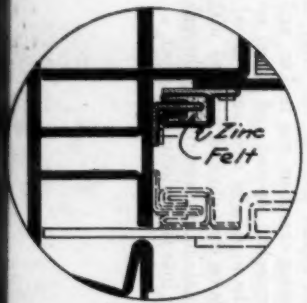
Test Manipulation

In making a test, an observer manipulated the valves so as to maintain a zero pressure drop between the collecting chamber and the room, as indicated by the sensitive pressure gage before him. An observer was required for such manipulation for each window under test. If sufficient observers were not available for making simultaneous tests on all windows, tests were made on at least two windows one of which was always the non-stripped window. Another observer made frequent observations of the anemometer indicator, pressure gages, meters, and wind direction. The wet- and dry-bulb temperatures were also recorded. The wind direction and velocity and barometric readings were later obtained from the weather bureau for the period of the test.

It was hoped to obtain tests with wind velocities perpendicular to the window ranging up to 30 miles an hour but it was soon found, however, that satisfactory wind was not to be had excepting at very infrequent intervals, and then the velocity was never very high.

A large number of tests were made with pressure drops through the window created by exhausting air from the collector chambers. Pressure drops equivalent to various wind velocities could easily be maintained for such tests. One observer controlled the pressure drop through each window under test by manipulating the valves while another observer recorded other observations. A few tests were also made by reversing the process—that is, by blowing air into the collecting chamber through the meter so as to give a desired positive pressure in the collecting chamber and a pressure drop through the window.

After an extended series of tests with the locked windows had been made, the seal on the man-hole covers in the collecting chambers was broken, and the covers were removed. The windows were unlocked, opened and closed several times, and then closed tightly after which the man-holes were again closed and sealed. A short series of tests was then made on the unlocked windows with artificial wind pressures only—that is, by maintaining a pressure drop through the window by exhausting air from or blowing air into the collecting chamber.



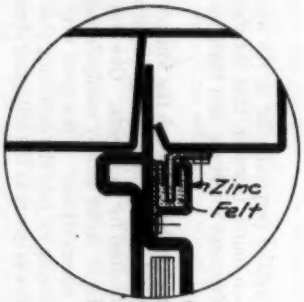
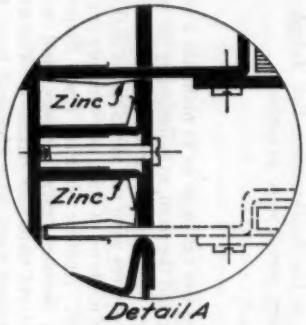
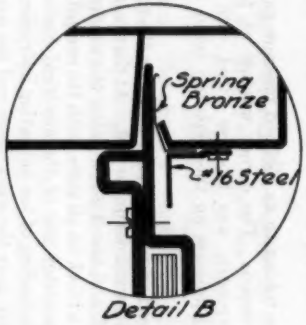


FIG. 9. CAMPBELL METAL WINDOW WITH ATHEY WEATHERSTRIPPING





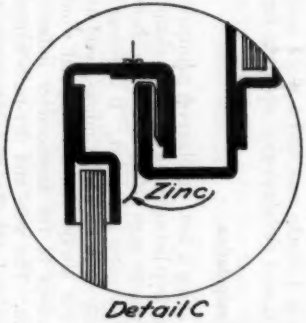


FIG. 10. CAMPBELL METAL WINDOW WITH CAMPBELL LEAKAGE-RETARDING IMPROVEMENT

Test Data

The object of the comparison of leakage through weatherstripped and non-weatherstripped windows was to establish data regarding reduction in leakage, which might be expected from the application of any good weatherstrip, and was not to establish the relative merits of the four strips studied. This report is only concerned with the average leakage through the different weatherstripped windows and the numerical value of such averages only are given. It is, however, desirable in this report to illustrate the consistency of the data collected on the different windows, and for this purpose, all data collected on one weatherstripped window is shown. However, the scale showing the magnitude of the leakage is purposely omitted so that a direct comparison is not possible, even though the particular make of weatherstrip be ascertained.

Points on curves *C* and *D*, respectively, Fig. 13, are the results of tests with artificial wind pressures on the non-weatherstripped window, locked and unlocked.

The curve in Fig. 14 is a reproduction of curve *C*, Fig. 13, with the test points for natural wind pressures against the locked, non-weatherstripped window, plotted on it. The leakage is plotted against the pressure drop resulting from natural winds as observed at the sixth window.

Curves *A* and *B*, Fig. 15, show the leakage through one of the weatherstripped windows, locked and unlocked, respectively. The test points are for artificial wind pressures only, and are plotted to an unknown scale in order to avoid direct comparison.

Fig. 16 is a comparison of artificial wind pressure data and natural wind pressure data for a weatherstripped window. The curve is based on data obtained with artificial wind pressures; the indicated test points are for natural wind pressures. All points are plotted to an unknown scale.

Curves *A* and *B*, Fig. 13, are the averages of curves for all four weatherstripped windows for the locked and unlocked conditions, respectively.

Discussion of Results

The data in the curves, Figs. 13 to 16, indicate that consistent results can be obtained from tests on windows in an actual building. The data collected when artificial wind pressures were produced show a very consistent curve, even though tests were made under varying conditions and over a period of several weeks. The test points for natural wind pressures, Figs. 14 and 16, show that practically the same leakage results from a given pressure drop regardless of whether it is produced artificially or by a natural wind. Curves *A* and *B*, Fig. 13, the averages of all weatherstripped windows tested, show that the average of the leakage retarding devices decreased the leakage about 56 per cent for a 30 mile wind.

Although a direct comparison of the leakage through the various stripped windows is not possible in this report, it should be added that the maximum variation of any strip from the averages as given in curves *A* and *B*, Fig. 13, is little greater than might be expected by the application of the same strip to two different windows by different mechanics. The variation in leakage through the different stripped windows tested is of minor importance when compared to the great reduction in leakage resulting from the application of any of the strips tested.

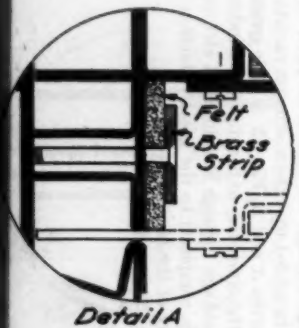


FIG. 11. CAMPBELL METAL WINDOW WITH CHAMBERLIN WEATHERSTRIPPING

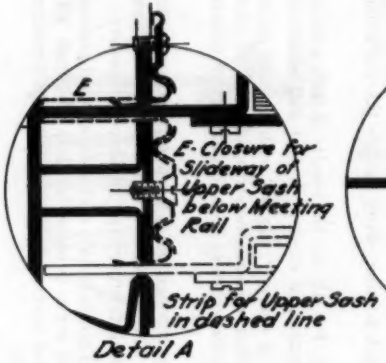


FIG. 12. CAMPBELL METAL WINDOW WITH MONARCH WEATHERSTRIPPING

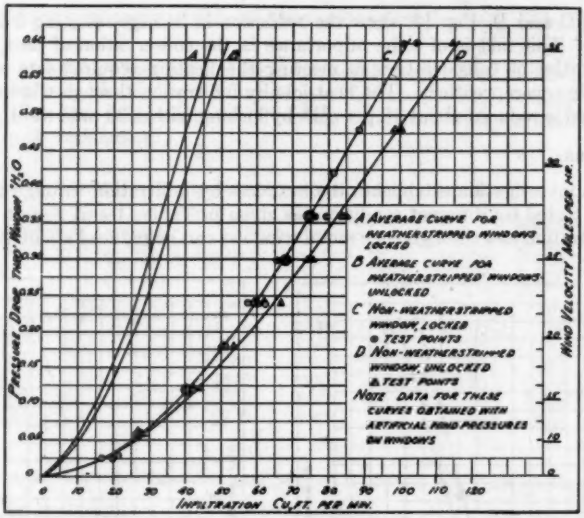

A
B
C
D
A AVERAGE CURVE FOR WEATHERSTRIPPED WINDOWS LOCKED
B AVERAGE CURVE FOR WEATHERSTRIPPED WINDOWS UNLOCKED
C NON-WEATHERSTRIPPED WINDOW, LOCKED ⊙ TEST POINTS
D NON-WEATHERSTRIPPED WINDOW, UNLOCKED △ TEST POINTS
NOTE DATA FOR THESE CURVES OBTAINED WITH ARTIFICIAL WIND PRESSURES ON WINDOWS
PRESSURE DROP THRU' WINDOW "H2O
WIND VELOCITY MILES PER HR.
INFILTRATION CU.FT. PER MIN.

FIG. 13. INFILTRATION THROUGH METAL WINDOWS WITH AND WITHOUT WEATHERSTRIPPING

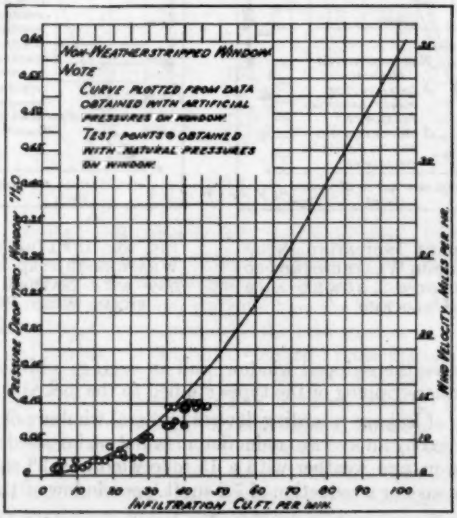

NON-WEATHERSTRIPPED WINDOW
NOTE
CURVE PLOTTED FROM DATA OBTAINED WITH ARTIFICIAL PRESSURES ON WINDOW
TEST POINTS ⊙ OBTAINED WITH NATURAL PRESSURES ON WINDOW
PRESSURE DROP THRU' WINDOW "H2O
WIND VELOCITY MILES PER HR.
INFILTRATION CU.FT. PER MIN.

FIG. 14. INFILTRATION THROUGH METAL WINDOWS WITH NATURAL AND ARTIFICIAL WIND PRESSURES

Curves *C* and *D*, Fig. 13, show the reduction in leakage resulting from locked windows. This fact is of some importance in the conservation of heat, and is a factor worthy of consideration in meeting the heating requirements of a large building in severe weather. The heat loss by infiltration through windows of the type tested is reduced about 10 per cent by locking with a 30 mile wind.

Conclusions

1. The investigation establishes the heat loss by infiltration through the metal windows tested for different conditions as given in Tables 1 and 2. It indicated that infiltration loss through such metal windows can be reduced about 10 per cent

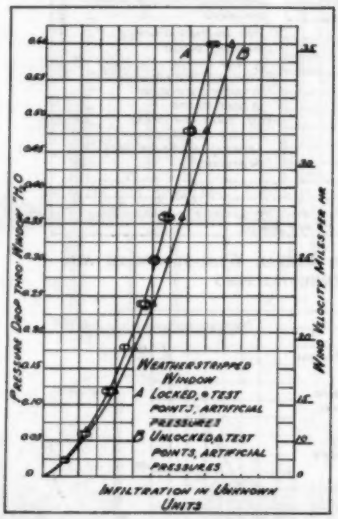


FIG. 15. CHART INDICATING INFILTRATION THROUGH WEATHERSTRIPPED METAL WINDOW LOCKED AND UNLOCKED

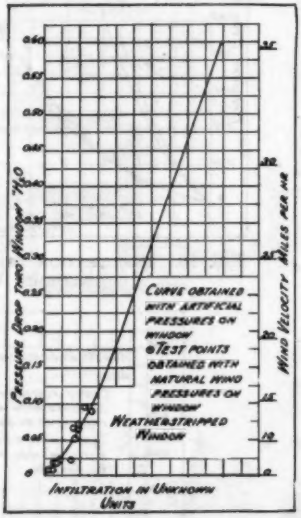

CURVE OBTAINED WITH ARTIFICIAL PRESSURES ON WINDOW
● TEST POINTS OBTAINED WITH NATURAL WIND PRESSURES ON WINDOW
WEATHERSTRIPPED WINDOW
INFILTRATION IN UNKNOWN UNITS

FIG. 16. INFILTRATION THROUGH WEATHERSTRIPPED METAL WINDOW WITH NATURAL AND ARTIFICIAL WIND PRESSURES

by locking an unweatherstripped window, and an average additional 56 per cent by applying weatherstripping of the types studied to the locked window.

2. Application of leakage retarding devices to metal windows of the type studied can be accompanied by an average reduction in radiation installed to meet the heating requirements in zero weather with a 15 mile wind of 0.28 sq. ft. per foot of crack around the sash or a reduction of 7.2 sq. ft. per window of the particular size investigated.

3. Determination of infiltration through windows in actual buildings is quite

feasible although much more difficult than making similar tests under laboratory conditions.

4. Data collected under natural wind pressures in an actual building are practically the same as those collected for artificial wind pressures. It may be assumed, therefore, that data collected under laboratory conditions with artificial wind pressures are quite satisfactory.

TABLE 1. INFILTRATION THROUGH METAL WINDOWS

Wind Velocity	Non-weatherstripped Window, Locked			Non-weatherstripped Window, Unlocked			Weatherstripped Window, Unlocked		
Miles per hr.	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation
5	660	832	3.5	660	832	3.5	210	265	1.1
10	1470	1852	7.7	1530	1928	8.0	600	756	3.2
15	2280	2872	12.0	2400	3025	12.6	1020	1285	5.4
20	3120	3932	16.4	3360	4235	17.7	1488	1875	7.8
25	4050	5105	21.3	4440	5595	23.3	1950	2458	10.2
30	4980	6275	26.2	5520	6960	29.0	2460	3100	12.9
35	6060	7640	31.8	6870	8660	36.1	3060	3858	16.1

TABLE 2. INFILTRATION THROUGH METAL WINDOWS PER FOOT OF CRACK

Wind Velocity	Non-weatherstripped Window, Locked			Non-weatherstripped Window, Unlocked			Weatherstripped Window, Unlocked		
Miles per hr.	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation	Leakage cu. ft./-hr.	Heat Loss B.t.u./hr. 0–70° F.	Sq. ft. Radiation
5	25.5	32.1	0.13	25.5	32.1	0.13	8.1	10.2	0.04
10	56.8	71.5	0.30	59.1	74.4	0.31	23.2	29.2	0.12
15	88.0	110.8	0.46	92.5	116.8	0.49	39.4	49.6	0.21
20	120.4	151.8	0.63	129.7	163.4	0.68	57.5	72.4	0.30
25	156.3	197.0	0.82	171.4	216.0	0.90	75.3	94.9	0.40
30	192.2	242.2	1.01	213.0	268.7	1.12	95.0	119.9	0.50
35	233.8	294.9	1.23	265.0	334.3	1.39	118.1	148.8	0.62

DISCUSSION

G. B. NICHOLS: I think this paper is very timely on account of the number of skyscrapers being built at the present time throughout the country. There is one phase of the paper that is still unfortunate. I think the paper carries a little too much of an advertising nature and you might get the idea (not that I have anything against it) that the Campbell window is the best window to use in skyscraper work. The title of the paper is not quite covered by the material of the paper. It only touches one phase, that of infiltration through windows. I recently have been connected with several skyscrapers and have my office in one. I was led to make some studies around that building, the Tribune Tower in Chicago. There was a paper several years ago at one of our Atlantic City meetings on the neutral zone in skyscrapers. I think it has been a subject that has been little thought out. I had my office on the 19th floor of the Tribune Tower in Chicago. It was almost impossible to keep that room at 70 deg. Most of the time it varied from 55 to 60. I had thermometers in the room continuously in winter weather. In other

words, that office appeared to be in the neutral zone. On the bottom floors we had the infiltration of air and on the upper floors the outgoing air.

There are no papers in existence that in any way approach that subject of how much radiation shall be put into the bottom floors of a skyscraper, how much on the top floors with the same type of rooms.

To add to this information, in a recent skyscraper that has been built in Chicago and nearing completion at the present time, the building was laid off with the usual metal windows. That building contains approximately 50,000 square feet of radiation. Campbell windows were put in that building. One of the great arguments was that the saving in radiation would be more than offset, or would more than offset the extra cost of the Campbell windows. The extra cost in that building was approximately $5000. The engineers were asked to revise the plans, the radiation to meet the Campbell window infiltration. The reduction on the plans was about 10 per cent in radiation. The actual cost of the reduction was about 28 cents a square foot which amounted to about $1300. So that the extra cost of the windows was approximately $3700. They cannot substantiate the special windows and their extra cost on the saving in radiation. There is no leg to stand on at all. The leg to stand on is the saving in fuel.

There was one other point that is well worth considering bringing under this head, the argumentative point of having a control on the downfeed riser. Generally speaking skyscrapers are downfeed system and at the top of each riser inserting a control valve, an air control valve, and having that operate by air pipes to the boiler room. There are a number of buildings in Chicago that have been built along that line. The engineer turns off the risers on the sunny side of it during the daytime. In other words, he follows the sun around the building. If the sun is in the east he will cut off a few of the risers on the east side and as the sun goes around the buildings he will cut off other risers. There is quite a chance for saving along that line and it should come under this head.

No. 804

THE SEMI-ANNUAL MEETING, 1928

ONE of the largest summer meetings ever held of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS was the 34th Semi-Annual gathering held at the West Baden Springs Hotel, West Baden, Ind., June 26 to 29.

Of the 250 registered it was noticeable that a great majority were members who took a keen interest in the proceedings. The sessions were presided over by Pres. A. C. Wlliard, professor of mechanical engineering, University of Illinois, and under his direction it was found that each subject was discussed in detail and plenty of time remained to participate in the entertainment features which were directed by C. R. Ammerman of Indianapolis, chairman of the Committee on Arrangements.

Report of Committee on Heating and Ventilating Garages

In the interest of fire protection, proposed regulations governing the construction and operation of bus garages prepared by the Committee on Garages of the *National Fire Protection Association*, were adopted as a tentative standard at the annual meeting of the Association in Atlantic City, N. J., May 7–10, 1928.

ABSTRACT

The Code as submitted for tentative adoption after revision from the preliminary form in which it was presented last year, covers the construction of bus garages, with limitations as to height and area and other features, drawn with consideration of the high unit value of the bus and the serious impairment of transportation facilities resulting from fires in bus garages. The regulations provide for the separation of hazards, such as repairing operations, painting and heating plants from the main garage area, and for mechanical ventilating systems wherever ample natural ventilation is not obtainable. Fire protection, the storage and use of flammable liquids, housekeeping and various operating details are also covered in the regulations.

COMMITTEE

H. E. Newell, *Chairman*

K. W. Adkins, F. H. Alcott, E. P. Boone, K. B. Brier, E. K. Campbell, A. M. Daniels, W. K. Estep, R. H. Goodwin, Louis Harding, G. C. Hecker, W. F. Hickey, A. D. Knox, R. C. Loughead, Ray Nelson, I. Osgood, R. E. Plimpton, A. M. Schoen, H. S. Smith, John Stilwell, J. F. Templin, J. S. Trump, W. B. White and Wm. P. Yant.

The abstract from the code consisting of Sections 15 to 19, given in the following paragraphs, quotes the regulations covering heating and ventilation and is submitted to the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS for tentative adoption. In the preparation of this work E. K. Campbell represented

the Society and he was assisted by Thornton Lewis, W. H. Carrier and E. B. Langenberg.

Section 15

(*a*) Garage heating plants should preferably be located in a detached building. If within the garage, the heating plant shall be placed in a separate room used for no other purpose and cut off horizontally and vertically from all other parts of the building by reinforced concrete walls not less than 6 in. thick, or masonry walls not less than 8 in. thick.

Openings in such walls shall be restricted to those necessary for heating ducts. There shall be no opening between the firing space of any heating apparatus and the garage. Entrance to room containing the heating plant shall be from the outside only.

All air entering the heat generating plant for combustion purposes shall be drawn from outside the building.

(*b*) Sufficient heating capacity shall be provided to permit the operation of the ventilating system in the coldest weather, and at the same time maintain an inside temperature of not less than 40 deg. fahr.

(*c*) No method of heating shall be used which permits flame in the garage or in any communicating room.

(*d*) Motors used in connection with heating system shall be of the constant speed type. All switches for such motors shall be of approved design and installed in compliance with the National Electrical Code. Three phase motors shall be protected against single phase operation.

(*e*) The use of steam plants heated by either direct or indirect radiation is permitted, provided the requirements of the ventilating section of these regulations are complied with.

(*f*) Unit heaters employing steam generated at some other point are permitted provided the requirements of the ventilating section of these regulations are complied with, and provided further that fans and motors shall be located in compliance with the National Electrical Code.

(*g*) Steam blast systems with central fan and coils together with ducts are permitted provided the requirements of the ventilating section of these regulations are complied with. The heating coils of such systems shall be separated from the firing space by masonry walls at least 8 in. thick.

(*h*) Warm air furnace blast systems of heating are permitted provided the requirements of the ventilating section of these regulations are complied with. The air space surrounding the furnace within the heating chamber shall be separated from the firing space by a masonry wall at least 8 in. thick. This wall may be pierced only by the feed and ash pouches of the furnace.

(*i*) Recirculation of air within the garage is permitted provided the provisions of the ventilating section of these regulations are complied with. In addition to the air drawn from the outside as required by *Section 16* (*d*) the volumetric contents of the garage shall be recirculated once every 20 minutes.

(*j*) In central furnace fan plants, 5 per cent of the air moved by the fan shall be taken direct from outside of the building through a duct which shall deliver the outside air to a point near the floor on which the fan rests; the duct shall be open at all times and the air supply which it provided shall be without control.

(*k*) All fans used for recirculating air within the garage or exhausting air from the garage shall be of non-sparking type.

Section 16. Ventilation of Storage Sections

(*a*) These regulations shall apply to the following garages:

1. Garages housing 35 or more motor vehicles with 3 or more walls pierced with openings.

2. Garages housing 25 or more motor vehicles with 2 walls pierced with openings.

3. Garages housing 4 or more motor vehicles and located above ground but having less than 2 walls pierced by openings and exposed to the outside.

4. Garages housing 4 or more motor vehicles and located below the level of the ground.

(*b*) Natural ventilating may be employed where it is practicable to maintain open windows or other openings at all times. Such openings shall be distributed as uniformly as possible in at least two outside walls. The total area of such openings shall be equivalent to at least 5 per cent of the floor area.

(*c*) Where it is impracticable to operate such a system of natural ventilation, a mechanical system of ventilation shall be provided. This system may be combined with the heating system or may be an entirely separate installation.

(*d*) Positive provision shall be made for either the inlet of 1 cu. ft. of air per minute from out-of-doors for each square foot of floor area, or for removing the same amount and discharging it to the outside.

(*e*) For the purpose of the regulations, positive means of handling air shall be understood to mean a power-driven fan of sufficient capacity to move the required volume of air.

(*f*) Where positive systems of exhausting air are used, the exhaust openings shall be not more than 24 in. above the floor and shall be not more than 50 ft. apart.

(*g*) Garages having a capacity of not less than 4 or not more than 35 cars within the scope of these regulations may consider air exhaust stacks as positive, provided they have not less than 15 sq. ft. of steam heating surface for each square foot of duct area, and not less than 1 sq. ft. of free area through both heating coil and duct for each 350 sq. ft. of floor area. Such an exhaust duct shall discharge above the roof and extend in any case to a height of not less than 15 ft. above the heating coils.

(*h*) Where mechanical systems of introducing outside air are used, and where air is recirculated the air shall be delivered horizontally and in sufficient volume and with sufficient velocity to secure distribution to all parts of the building. The height of the air inlet opening shall be such that the air will be discharged above the top of the vehicles.

(*i*) All duct openings, either supply or exhaust, shall be covered with $^1/_4$-in. mesh screen.

(*j*) The passing of air ducts through fire walls shall be avoided wherever possible. Ducts shall be installed in accordance with the regulations for the installation of blower and exhaust systems.

Section 17. Repair Shops

(*a*) Repair shops shall be veniltated as required for garage storage sections, except that mechanical means shall be provided for both the inlet and exhaust of 1 cu. ft. of air per minute per square foot of floor area.

(*b*) In connection with engine testing it is recommended that the engine discharge direct to outdoors through a straight duct or pipe of incombustible material, and of suitable size, installed as an extension of the exhaust pipe or muffler in which case the mechanical system for inlet or mechanical system for exhaust may be omitted.

Section 18. Fuel Burning Appliances

Steam generators for tire vulcanizing, for oil and grease removal and for purposes other than space heating water heaters, and other fuel burning appliances such as forges shall not be installed within bus operating section or within carpenter or paint shop.

Section 19. Inspection and Repair Pits and Trestles

Elevated trestles or hoists are preferable for this service. If pits are used, they shall be continuously ventilated by a system independent of the main garage ventilating system. Such pits shall be cleaned at least daily and no accumulation of oil and grease permitted. Permanent illumination shall be provided.

XUM

DISCUSSION

E. S. HALLETT: I have no particular objection to the report that has been brought forth, but it is not complete, as yet, because the protection of health which I consider the most important part of it, has not been included.

As our Research Committee has already stated that probably in the near future the Research Laboratory will take up the question of determining the condition of health in garages, I think that this ought to stand by until we have that information from the Research Laboratory.

I am willing to approve this, as far as it goes, but with the understanding that it is to be completed as soon as sufficient data have been given us.

THORNTON LEWIS: If the chair might be allowed to say something on that point, (as I happen to be a member of the Committee), this code is a code of minimum requirement for garages for fire prevention. As such, if there is no objection to the principles involved in this code, we can proceed and adopt the code; then later we can consider a code for health requirements in garages. That is another far-reaching step.

F. A. KITCHEN. I understood from looking over the code that the ventilation section is a basic part of this code. If there are to be revisions of this section as indicated by the chairman, we should not approve it as to basic principle.

MR. LEWIS: The ventilation required in this code as presented is for the purpose of fire prevention, not for the purpose of protecting health.

F. PAUL ANDERSON: We are voting on the question of a progress report. We accept this progress report, and there is no code to be adopted, as I take it. Is that right?

DR. E. V. HILL: Mr. Chairman, I have not read the code just presented but if I understand Mr. Campbell correctly, this is entirely a code of fire prevention. What has this organization to do with fire prevention, I mean primarily as a basis for the code? We are interested in heating and ventilation, and it seems to me those things should come first. We have numerous fire prevention organizations to care for fire prevention codes, and why should we start in by adopting something which seems to me entirely foreign to our activities?

Another thing: A good many people will gain the impression, without studying this matter in detail, that this is a complete code adopted by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, but it is only a fire prevention measure. I think it is a questionable procedure to adopt it at this time in its present unfinished form.

J. C. MILES: I think in view of the fact that our part of heating and ventilating garages has a great deal to do with the fire hazard, I am inclined to feel that we ought to take some definite action on it for the reason that we will have to cooperate with the Underwriters, and without the protection that we give, why, the Underwriters will be practically in a position where they would specify that no heating system shall be put in a garage building, no kind of fire shall be put in a garage building, etc., so if we are going to offer to the Underwriters our suggestions, I believe after reading this code over, it is excellent, and a thing we should do.

P. E. FANSLER: I want to inject a word here because I happened to be in at the start of this. When Mr. Newell of the *National Fire Protection Association* desired some technical information on the ventilation of garages, having respect only to explosion risk and having nothing to do with the protection of health or life, he came to this Society for information. The committee of the *National Fire Protection Association* have tentatively accepted this as their code, not ours, and they will not finally accept the recommendation of our Committee until the Society has backed up the Committee report, and that is the essence of the whole thing.

This is not a code for our use; it is a code of assistance for them, and we are merely acting as advisers to them.

DEAN ANDERSON: In view of the fact that the reader of the paper stated that they are still working on the code, and in view of what Dr. Hill has said, that adopting this at the present time might be construed as adopting a code in a fixed form, I offer a substitute motion that this code be referred to the Committee for further consideration.

E. B. LANGENBERG: I don't think that is necessary, Dean Anderson, for this reason: All we want is the approval of the progress report. We are not adopting the code. We are adopting the approval of the report up to this point. It gives us a standing in that joint committee with which we are working. We need action of this kind for that reason.

We have been trying to get a contact with the *National Fire Protection Association*. This is a good contact. If we don't carry on they will legislate concerning fire hazards and some of it is working an injury to a certain section of this group at the present minute.

H. M. HART: As I understand it the Society has been asked to help in giving certain information necessary for fire prevention in garages. They want the endorsement of this Society of the Committee's report. I think that if we are willing to appoint a committee to go ahead and do the work necessary to prepare such data, it is up to the Society to either accept the Committee's recommendation or reject it. We should endorse it. Otherwise, why should we appoint a committee.

MR. KITCHEN: The chairman of this committee advises us that there are other features of the present code to be revised. As long as changes are being made, would it not be advisable to follow Dean Anderson's suggestion and refer this back to the committee without approving it?

E. K. CAMPBELL: Replying to Dr. Hill, the history of the thing is this: The *National Fire Protection Association* was asked by the Underwriters to prepare a code for the construction of heating and ventilating systems for garages from the standpoint of minimizing fire loss. They asked the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS to appoint a representative to work with them.

At the meeting a year ago the present committee was appointed as an advisory committee to consult with and advise our representative on the garage committee of the *National Fire Protection Association*. This is a report of the Advisory Committee of the work done thus far, which is possibly a compromise between all the committees involved, and we are asking, not the adoption of the code, but what might

be called instructions as to whether we are working on the right line. If we are not working on the right line or lines that suit this Society, we want to know it, so that we can start over, or appoint another committee. If we are working on the right line, we want you to say so, so we can go to the *National Fire Protection Association* with your backing.

I move the tentative adoption of this code as presented.

MR. MILES: I second the motion.

DR. HILL: What does "tentative" mean?

MR. LEWIS: In this instance I take it that it means that the committee is working along the right lines, that the Society is in harmony with their general ideas. At a later date a definite specific code will be submitted for adoption.

MR. CAMPBELL: I want to emphasize again the fact that the committee wants any suggestions that any of you can make that will help to make this code better in your opinion. Give them to us in writing, and, whether in detail or what they are. We want them.

MR. LEWIS: Send those communications to Mr. Campbell in Kansas City, or to the Secretary of the Society.

Resolutions on J. H. Kinealy and W. S. Timmis

Two resolutions were offered on recent deaths of the Society's Past-Presidents, Walter S. Timmis of New York and J. H. Kinealy, St. Louis.

Mr. Hallett paid a tribute to Prof. Kinealy and then presented the following resolution:

WHEREAS, the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS has again been deprived by death of one of its cherished members and past-presidents, Prof. J. H. Kinealy, of St. Louis, Mo. It is deemed most fitting that attention be called to the fine qualities of the man and engineer, and to the services rendered to this society and to the fund of engineering knowledge in general.

As professor of engineering at Washington University, during its early days, he designed a heating and ventilating plant for the university manual training building and after 40 years, is still giving excellent service. To Professor Kinealy belongs the distinction of designing the first all-blast heating system in St. Louis schools, which started the standard practice of using mixing dampers for warm air and tempered air.

When he retired from this educational work to take care of his consulting business which was the first in that part of the country, his knowledge of the legal phases of engineering carried him rapidly into a practice of the law of patents and other allied legal business. He pioneered in this form of engineering and succeeded, as in all the undertakings to which he put his hand.

He was a most friendly and helpful counselor to your men who sought his advice in their early struggles for recognition. He often laid aside his most important brief to spend an hour in fatherly advice and in coaching a young engineer that he might be spared the pit-falls that beset the early years. On a recent appearance before the St. Louis Chapter he talked on "The Idealism and Ethics of the Engineer." Although he was not often present in our meetings, he was in touch with our progress and his information was up-to-the-minute. It is a great satisfaction to contemplate a life of such rare value and we must recognize our indebtedness to this life.

Therefore Be It Resolved: That we extend to his wife and family an expression of our sincere sorrow in their bereavement.

And Be It Further Resolved: That the resolution be spread upon the minutes and a copy be sent to his family.

W. H. Carrier said that before presenting a formal resolution he wished to say a few words regarding a valued friend, the late Walter S. Timmis of New York.

I have known Mr. Timmis for many years, since 1902. Aside from being a Past-President he was always very active in the Society. In his contacts with the members of the Society he has always shown his great fairness and his friendliness, especially to the younger engineers, a fact that to me is of great interest since my contact with him was perhaps a turning point in my engineering career.

To show something of the advanced thought and foresight of Mr. Timmis I may state that as far as I know he was one of the first engineers, if not the first engineer, to conceive the possibility of special air treatment for industrial purposes now known as air conditioning. It was in 1902 that Mr. Timmis, then a young engineer in New York City, brought to J. I. Lyle, my present associate, the problem of humidity control and cooling in summer of a lithographing plant located in Brooklyn. He had studied the difficulties encountered in the lithographing process especially during the humid summer months and in the cold and dry winter months. He had worked out, or at least visualized, the possibility of some mechanical system which should be devised which would maintain such conditions as he knew were required in this industry. It was with this problem that he came to Mr. Lyle, as a fan specialist, for its solution.

Mr. Timmis and Mr. Lyle decided insufficient data were available on the method of air treatment required and that the problem should be made the subject of experimental research. Mr. Timmis had two problems in mind. One was the use of a concentrated solution of calcium chloride for the dehydration of the air, and the other was the use of cooling coils to condense the moisture out of the air. This task was referred to me as research engineer for the Buffalo Forge Co., and it was through this contact with Mr. Timmis and due to his insight into the requirements and possibilities of these applications that I became deeply interested in the problems of atmospheric moisture. It was from this experimental work conducted at his suggestion and with his assistance and encouragement that the foundation was laid for what is known today as air conditioning. It is for this reason that I feel the Society, as well as myself and associates individually, owe a great debt to Mr. Timmis for his foresight and his vision as to the possibilities of this development of our industry, and that his name should be permanently linked historically with this development.

As a friend I have valued him ever since this early meeting. He was a friend to a great many members of this Society and I think they all feel very sorely his loss.

I would like to make as a formal resolution, the following:

WHEREAS, It has been the will of the Almighty to take from our midst our esteemed friend and valued associate, Walter S. Timmis and

WHEREAS, From his earliest associations with this Society he has shown his worth as an engineer and a loyal friend, be it

Resolved: That we extend to his wife and family the expression of our sorrow and regret in their bereavement, which we feel so deeply.

Be It Further Resolved: That this motion be spread upon the minutes and that a copy be sent to his family.

PROGRAM 34TH SEMI-ANNUAL MEETING

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

WEST BADEN SPRINGS HOTEL

West Baden Springs, Ind., June 26–29, 1928

Schedule of Daily Events

Tuesday, June 26, 1928

9:00 A.M. Registration
Committee Meetings

12:45 P.M. Luncheon for Officers and Authors

2:00 P.M. Greeting by Pres. A. C. Willard
Development of Gas Heating for Homes, by W. E. Stark
Methods of Calculating Cost of Gas Heating, by A. E. Stacey, Jr., and W. B. Thornton
Operating Data on Federal Buildings, by Nelson Thompson

7:30 P.M. Council Meeting

8:00 P.M. Informal Reception and Dance

Wednesday, June 27, 1928

8:00 A.M. Meeting—Committee on Heating and Ventilation Exposition, H. P. Gant, *Chairman*

9:30 A.M. Report of Nominating Committee, E. K. Campbell, *Chairman*
Warm-Air Heating System for Industrial Buildings, by J. C. Miles
Relative Consumption of Various Solid Fuels in Residence Heating, by V. S. Day
Domestic Oil Burner Design and Performance, by W. C. McTarnahan
Coefficients of Heat Transfer as Measured under Natural Weather Conditions, by F. C. Houghten and C. G. F. Zobel
Heat Transfer through a Roof under Summer Conditions, by F. C. Houghten and C. G. F. Zobel
Heat Transmission Research, by F. B. Rowley, F. M. Morris and A. B. Algren

2:30 P.M. Golf Tournament (Research Cup)

2:30 P.M. Ladies Bridge and Tea

8:00 P.M. Meeting of Technical Advisory Committee on Temperature, Humidity and Air Motion, W. H. Carrier, *Chairman*

8:00 P.M. Moving Picture Film (White Sulphur and New York Meetings)

Thursday, June 28, 1928

9:30 A.M. Discussion of Code of Boiler Rating and Selection
Discussion of Code for Heating and Ventilating Garages
A Study of Dust Determinators, by F. B. Rowley and John Beal
Methods of Air Distribution, by L. L. Lewis
Refrigeration as Applied to Air Conditioning, by R. W. Waterfill

1:30 P.M. Meeting—Guide Committee on Heat Losses from Buildings, F. B. Rowley, *Chairman*

2:30 P.M. Golf Tournament (Men)

2:30 P.M. Trip to Marengo Cave for Ladies

7:00 P.M. Semi-Annual Banquet and Dance

Friday, June 29, 1928

9:30 A.M. Air Leakage through a Pivoted Metal Window, by F. C. Houghten and M. E. O'Connell

The Weathertightness of Rolled Section Steel Windows, by J. E. Emswiler and W. C. Randall

Effect of Storm Windows and Frame Calking on Infiltration around and through Windows, by W. M. Richtmann and C. Braatz

Heating and Ventilating Problems of Gas Cell Manufacture for Air-Ships, by D. E. Humphrey

COMMITTEE ON ARRANGEMENTS

C. R. AMMERMAN, Indianapolis, Ind., *Chairman*

F. Paul Anderson, Lexington, Ky.

J. J. Kissick, Cleveland, Ohio

RECEPTION COMMITTEE

J. D. Hoffman, Lafayette, Ind., *Chairman*

R. W. Noland, Lafayette
B. E. La Follette, Indianapolis
C. H. Hagedon, Indianapolis
S. E. Fenstermaker, Indianapolis
H. C. Murphy, Louisville
C. N. Warren, Indianapolis
C. C. Shipp, Indianapolis

REGISTRATION COMMITTEE

R. W. Noland, *Chairman*
W. C. Bevington
V. Hutzel

LADIES' COMMITTEE

C. H. Hagedon, *Chairman*
S. H. Perham
J. M. Rotz
H. B. Stitt

HOTEL AND TRANSPORTATION

B. E. La Follette, *Chairman*
T. W. McMahon
G. Williams

GOLF TOURNAMENT COMMITTEE

S. E. Fenstermaker, *Chairman*
M. H. Hutzel
R. Cotton
R. C. Bolsinger

ENTERTAINMENT COMMITTEE

C. N. Warren, *Chairman*
R. N. Downs
J. C. Lewis
R. F. Prox
Norman Ascher

PUBLICITY COMMITTEE

H. C. Murphy, *Chairman*
W. G. Bergner

FINANCE COMMITTEE

C. C. Shipp, *Chairman*
G. A. Voorhees

No. 805

DEVELOPMENT OF GAS HEATING FOR HOMES

By W. E. STARK,[1] CLEVELAND, OHIO
MEMBER

DURING one of the sessions of the 1927 Annual Meeting it was W. H. Carrier who made a statement to the effect that after a certain period progress in an art tended to come to a standstill, awaiting the opening of a new avenue that would lead the way to a new series of developments. He cited the art of illumination, in which the possibilities of lighting with oil and lighting with gas seemed in turn to reach their limit; only to be followed by the development and refinement of a new illuminating medium, electricity.

The same tendencies can be seen in the art of heating, particularly in the fuel-burning group of the great general class of heating appliances. Solid fuel long ago ceased to present any possibilities of further radical improvement in utilization methods. Liquid fuel opened up a new avenue of development, the end of which has not yet been reached. Now a third avenue of development, gaseous fuel, has been entered and it bids fair to lead farther along the road to perfection than either of the two roads just mentioned.

Contrary to the impression that might have been engendered by the two preceding paragraphs, heating buildings with gas is no new thing. Natural gas has long been used as a fuel for all heating purposes in those parts of the country that are blessed with a plentiful supply. Pennsylvania, West Virginia, Ohio and Kentucky have enjoyed natural gas for many years. Indiana now regrets that it enjoyed its supply of natural gas in a too care-free manner, exhausting it by prodigal waste. In the Southwest new supplies of natural gas have lately been developed and it is to be hoped that they will be conserved for future generations. With the new fields that are being developed the production of this supposedly dwindling resource is actually increasing. Fig. 1 shows the annual production of natural gas for the last nine years, taken from Bureau of Mines data and estimated for 1927. It also shows the annual domestic and industrial consumptions for the same period. The difference between the total production and the total of the domestic and industrial consumptions represents the gas used for carbon-black production and in the fields.

Fig. 2 shows how the average consumption per domestic consumer of natural

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[1] Engineer, Bryant Heater & Mfg. Co., Cleveland, O.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.

gas has varied in the past few years and Fig. 3 shows how the domestic rate has varied. Industrial rates have varied in the other direction, showing a decrease. Industrial rates are lower for gas as well as for any other product sold in wholesale quantities, on account of the greatly reduced cost of delivery.

It is impossible to determine very accurately just what proportion of the gas

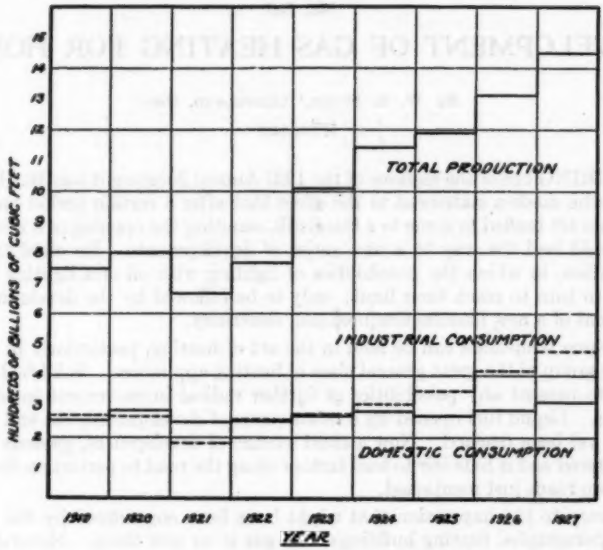

FIG. 1. NATURAL GAS 1919–1927

represented by the chart of Fig. 1 was used for heating purposes. Some of it is included in the domestic consumption while a portion is included in the industrial consumption. It is only when gas companies have special rates for building-heating purposes that the amount of gas sold for heating can be determined. Most manufactured gas companies that sell gas for heating purposes grant special heating rates, while very few natural gas companies follow this practice. It will be noted, however, from the domestic consumption chart of Fig. 1, that it is only within the last few years that the domestic consumption has begun to increase very rapidly. This increase may in part be due to the increasing tendency of natural gas companies to encourage the heating load.

The extremely low rates for natural gas which prevailed in all districts until a few years ago were not conducive to the development of refined gas-burning appliances. The almost universal practice was to use conversions, by which is meant a coal-designed appliance such as a boiler or a warm air furnace, with gas burners applied to it. For reasons which every engineer at all familiar with the combustion

of coal and gas understands, gas cannot be burned efficiently in such an appliance and at the same time secure the rated output of the boiler or furnace. However, with low gas rates, no abuse that can be inflicted on the fuel will build up a very large gas bill. With the extremely low natural gas rates that prevailed a few years ago a conversion was an economical arrangement from the standpoint of the user; although from the standpoint of the conservation of natural resources it was decidedly uneconomical.

Perhaps it was not increasing rates for natural gas so much as the fear of shortage during cold spells of long duration that impelled the development of high-grade gas-burning appliances for heating purposes. The modern gas boiler and furnace were born in the natural gas belt in the days of cheap gas. Cold weather peaks, taxing the capacity of the existing distribution facilities rather than the production capacity, causing prolonged periods of low pressure, were an inducement for the development of appliances that would operate at full capacity under very low gas-supply pressures. Something over twenty years ago boilers and furnaces designed for the sole purpose of burning gas began to make their appearance in the natural gas belt of the eastern part of the country.

The use of manufactured gas for building-heating purposes dates only from 1914. It did not start primarily from the desire of gas companies to increase their sales or from the desire of appliance manufacturers to find a new field for their product. Both gas companies and appliance manufacturers felt that manufactured city gas was altogether too high priced to be used as a fuel for building-heating purposes. However, in 1914 a far-sighted gas company in a rather large eastern city contracted for a supply of coke-oven gas from a nearby steel mill at an unusually low price. They gambled on finding a market for this gas and the thought of using it for heating homes came to their minds. Vague reports had been heard of a boiler designed solely for gaseous fuel, manufactured out in the natural gas belt. The manufacturers of this boiler were with some difficulty persuaded to cooperate with the gas company in adapting their product to use with manufactured gas. Such is the reluctance of the human mind to accept new things.

Today that gas company has 1700 heating installations on its lines, heats 1.12 per cent of all the homes in the city, and sells 5.6 per cent of its annual output for building-heating purposes.

The problem that is uppermost in the minds of the gas companies that are contemplating embarking in the heating business seems to be that of load factor. Heating is a very seasonal load to be sure. Without going into the very large number of items that must be considered in determining whether a given class of load is desirable for a gas company to have on its lines, such as fixed charges on the producing and distribution system, diversity and demand, it might be interesting to point out that every industry that is related to heating works under the same seasonal handicap. The seasonal character of the heating load is felt and imposes its relatively low load factor on coal miners, mine owners, railroads and coal dealers. That load factor is merely a scarecrow waiting to be stripped of its rags and is demonstrated forcibly by the fact that the last *American Gas Association* rate list shows 208 communities in the United States in which special heating rates are granted by the companies supplying manufactured gas. This list shows gas rates for a total of 1019 communities. In 20.2 per cent of them gas is sold for heating purposes at a rate lower than the usual domestic rate.

The effect of domestic heating on a gas company's domestic load is demonstrated by a brief analysis. Assume that a community has 10,000 domestic meters and that the average annual gas consumed per meter is 40,000 cu. ft. of 535 B.t.u. gas. Among these 10,000 domestic consumers there will be a certain number of what might be termed average prospects for residence heating, living in residences having a heating demand of about 350 sq. ft. of direct steam radiation. In a latitude where the annual heating season amounts to 6000 degree-days, the 535 B.t.u. gas consumed to supply 350 sq. ft. of direct steam radiation during the normal heating season will amount to about 385,000 cu. ft. In other words, one heating installation will have an annual demand equivalent to 9.6 average domestic consumers. If 100 domestic consumers, representing 1 per cent of the total, can be persuaded to heat their homes with gas, the company's annual domestic distribution will be

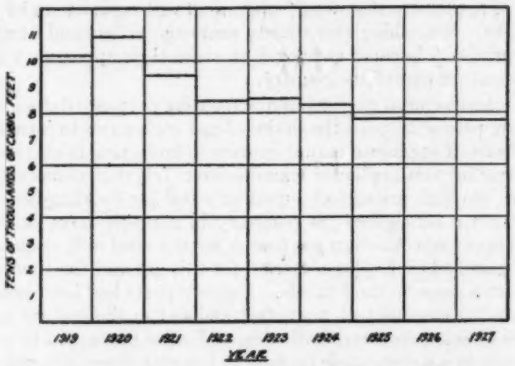

FIG. 2. AVERAGE NATURAL GAS CONSUMPTION PER DOMESTIC CONSUMER

increased by 9.6 per cent. Residence heating by 2 per cent of the domestic consumers will increase the annual domestic consumption 19.2 per cent. Residence heating by a little over 10 per cent of the domestic consumers will double the annual domestic sales. This analysis demonstrates in a crude way why gas can be sold for heating purposes at a lower rate than it can be sold for other domestic uses.

With manufacturing and distribution costs as they are at present, and with rates governed by those factors, gas is by no means a universal fuel for heating when considered from an economic standpoint. Considering first the economic phases of heating residences and limiting our attention to manufactured gas, it is rather generally assumed that the market for gas as a residence heating fuel is limited to those home-owners who have annual incomes of $5000 or more. Notice that the term "home-owners" is used. The owner of a tenant house is not inclined to equip it with a gas-burning heating plant. The case that might be construed as an exception to this statement is that of the speculative builder who puts gas-burning equipment in a residence that is primarily built to sell. A number of well-

known speculative builders in larger cities, notably in Chicago, St. Louis and Washington, have followed this practice extensively.

A gas-burning heating plant that is installed with any reasonable degree of care has operating characteristics that can be determined very accurately. With no other heating equipment can laboratory conditions be so nearly duplicated in the actual installation. Draft conditions affect combustion to a very slight degree on account of the draft-reducing devices that are almost universally introduced into the chimney connection. There is no fluctuation in the quality of the fuel and the appliance is not at the mercy of an attendant of questionable ability. Therefore, the performance of a gas-fired heating system can be very accurately predicted. The greatest element of uncertainty encountered in estimating fuel consumption is the weather. Extremely accurate estimates can be made for the average season. It is probable that for no other fuel is it possible to gather such a wealth of data on heating cost as can be gathered relative to gas. All of the fuel used is metered and of necessity an accurate record is kept, not for a period of variable length, but for regular periods of thirty days' duration.

Gas companies interested in heating can either develop their own methods of estimating heating costs, based upon their observations of local installations, or if they have no installations they can use the method in the Society GUIDE or in other publications.

The impression must not be held that gas as a fuel for heating is suitable only for residence use. In larger applications it may have a real economic superiority over other fuels. The following are some of the elements entering into the operating costs of heating plants:

a. Interest on the investment for apparatus.
b. Depreciation on the apparatus.
c. Maintenance of the apparatus.
d. Rental value of the floor space for the apparatus and for fuel storage.
e. Attendance, including firing and superintendance.

TABLE 1. COMPARISON BETWEEN COAL AND GAS FIRED INSTALLATIONS

Item	Gas	Coal
Equivalent direct radiation (sq. ft.)	8500	8500
Cost of boilers (two units installed)	$4550.00	$3830.00
Interest on the Investment	$ 273.00	$ 229.80
Depreciation reserve (20 years)	123.67	104.10
Maintenance	50.00	250.00
Rental value for fuel storage:		
600 sq. ft. at 40¢		240.00
Attendance:		
2 firemen 35 weeks at $42.00 per week		2940.00
Superintendance	875.00	875.00
Fuel cost:		
52.5 lbs. coal per sq. ft. per year at $7.50 per ton		1672.50
900 cu. ft. of gas per sq. ft. per year at 75 cents per M.C.F.	5737.50	
Annual operating cost	$7059.17	$6311.40

f. Damage to premises and to work done therein due to dirt from heating.
g. Fuel cost.

In making the comparison in Table 1 it is assumed that the fuel used has no effect on the cost of the heating plant other than that of the boilers themselves and also assumed that the boilers take up equal space for either fuel.

Item *f*, in the tabulation of elements given, of course cannot be evaluated and might or might not be of vital importance.

Gas-burning heating appliances have developed along certain well-defined lines that lend themselves most readily to the characteristics of the fuel. The most

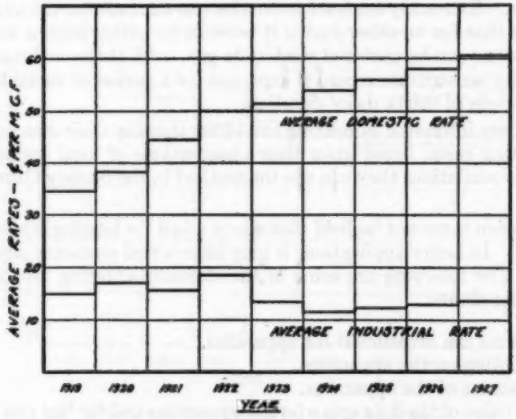

FIG. 3. NATURAL GAS RATES

satisfactory, cleanest and safest way in which to burn gas is with a blue, or Bunsen, flame. Since a Bunsen flame radiates very little heat, due to the blue color predominating, the only really effective heating surface is that with which the products of combustion make direct contact. In other words, the greater part of the heating must be by convection; wherein the streams of hot products of combustion that flow upward as convection currents are brought into intimate contact with the heating surfaces, to which they impart their heat by direct conduction. When heat is transmitted in this manner the transmission is most effective if each particle of hot gas passes by the heating surface at a minimum distance from it. This requirement is met by sectional construction, wherein the products of combustion are passed over the heating surfaces in thin streams, and it is along this line that the gas-burning appliance for central heating has been developed. This principle was recognized early in the progress of the art and in gas-burning appliances it can be carried to its fullest extent. Draft losses are limited to the friction of the moving stream of gas against the heating surfaces and since there are no draft losses due to

fuel beds, the friction losses within the gas passages can be allowed to run much higher than they can in a coal-burning appliance.

Gas is not inherently an efficient fuel when compared with other fuels. Due to its large hydrogen content, which appears both in the free and in the combined states, water vapor is one of the products of combustion. When 1 cu. ft. of the average manufactured gas is burned a little over 1 cu. ft. of water vapor is formed,

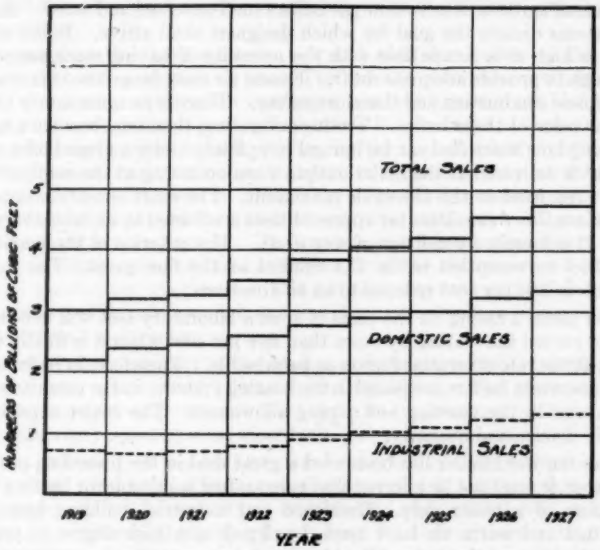

FIG. 4. MANUFACTURED CITY GAS 1919–1927

and when 1 cu. ft. of natural gas is burned a little over 2 cu. ft. of water vapor are formed. The heat content of this water vapor represents about 10 per cent of the total heat value of the gas. This heat cannot be reclaimed unless the products of combustion are cooled down to their dew point which is usually in the vicinity of 130 degrees. Since in a steam boiler the temperature of the escaping products of combustion must necessarily be above that of the steam delivered, it is impossible to cool the escaping flue gases to their dew point. Therefore 10 per cent of the heat in the fuel goes out unused in the water vapor. Five per cent is about the minimum amount that can be charged against dry stack loss. The maximum efficiency of a gas-burning steam boiler, with no allowances for radiation from the jacket, is therefore 85 per cent or less. Radiation losses will bring the efficiency closer to 80 per cent than to 85 per cent.

Attempts to condense the water vapor, which is possible in the cases of hot water boilers or warm air furnaces, lead to operating and maintenance difficulties on ac-

count of the corrosive effect of the liquid of condensation and also on account of the crystalline substances deposited by some manufactured gases. This in many cases eventually stops up drains and flue passages. We must, therefore, reconcile ourselves to this loss, which although it is recoverable in some cases, is recoverable only at a cost for added heating surfaces and for added maintenance that may outweigh the possible saving.

Contrary to the situation that exists with respect to coal-burning boilers, there is a very general agreement as to how gas boilers shall be tested and rated. Economic considerations dictate the goal for which designers shall strive. Boiler efficiency must be as high as is compatible with the necessity of having stack temperatures high enough to provide adequate draft. Excess air must be as low as is compatible with complete combustion and therefore safety. There is no uncertainty about the numerical value of these limits. Testing and rating, therefore, become a matter of determining how much fuel can be burned completely under a given boiler and how much heat is delivered at the boiler outlets when operating at the combustion rate that has been fixed as the allowable maximum. The draft condition imposed by the *American Gas Association* for approval tests conducted in its laboratory is very simple. It is merely a condition of zero draft. The criterion of the maximum allowable fuel consumption is the CO content of the flue gases. The maximum permissible is 0.04 per cent reduced to an air-free basis.

A boiler given a rating on the basis of such a laboratory test will neither fail to make, nor exceed that rating by more than five per cent when it is finally installed and fired at the rate determined upon as permissible. Therefore, in boiler selection the only uncertain factors are found in the heating system; in the correctness of the radiation and in the starting and piping allowances. The boiler capacity is an accurately determined quantity.

Because the word boiler has been used a great deal in the preceding paragraphs of this paper, it must not be inferred that gaseous fuel is suitable for heating through the medium of a boiler only. Residence and industrial building heating with gaseous fuel and warm air have been developed to a high degree of perfection. Lack of cleanliness, the universal objection to warm air as a residence-heating medium, is removed when a fuel which produces no dirt is substituted for dirt-producing fuels. The same economic and engineering principles govern when gas is applied to warm-air heating as govern when gas is applied to heating with steam and hot water. The number of high class residences heated with warm-air furnaces using gas fuel is significant. Many of these are residences which a few years ago would almost invariably have been heated with radiator heat. Extensive buildings, in which gravity circulation of warm air would be impossible, are heated with fan furnaces.

Direct-fired warm-air heating of small industrial buildings can be accomplished successfully with a large saving in floor space by putting the entire heating apparatus on the roof, an impossible procedure if solid or liquid fuel were being used.

Gaseous fuel is susceptible to the utmost refinements in automatic control. The responses to the demands for heat or the cessation of heat are instantaneous. Consequently, steam and water boilers and warm-air furnaces are almost invariably sold with full automatic equipment designed and built-in so as to cause the entire assembly to operate as a coordinated whole. Steam boilers are provided with

steam pressure control, shut-off valves operated by room thermostats, and safety devices to prevent gas from reaching the burners in the event of loss of water from the system. Water boilers are provided with water temperature control and gas shut-off valves responsive to the demands of room thermostats. Warm-air furnaces are provided with air temperature controls, gas shut-off valves controlled by room temperature, and fan furnaces can be controlled so as to coordinate fan operation and burner operation. In addition all appliances are almost invariably equipped with automatic pilots that operate to prevent waste of unburned gas in the event of pilot outage.

Gas-burning heating appliances are not sold over the counter to the same degree that coal-burning appliances are. The average individual putting up a new home, or the average corporation erecting a new building, are not likely to think of the possibility of gas as a heating fuel unless it is brought to their attention in some specific way, such as by advertising, by the recommendation of a satisfied user, or by personal solicitation on the part of a gas company or an appliance manufacturer. In some cases, to be sure, the user of fuel is consciously looking for an improvement on the fuel that he has been using, and seeks out gas instead of having it brought to his attention. The appliance itself is usually sold either by the gas company that is going to furnish the fuel or by the contractor who is installing the rest of the heating equipment. The gas company may sell either directly to the consumer or through a contractor and it may do the connecting itself or turn the job over to a contractor.

In any event the purchaser of the appliance is almost certain of having the gas company display a continued interest in its well-being. The gas company is a strong and long-lived corporation. This is in pleasing contrast with the situation that prevails with respect to some other fuels.

Gas as a heating fuel has its best days ahead of it. The surface has merely been scratched. It has been predicted that some day it will be looked upon as a crime to burn coal in the raw state. Distributing and burning coal as is done at present entails a three-fold waste. A very large fraction of the coal that is mined is used in transporting the remaining fraction. The greater part of the coal that is usefully applied is consumed in domestic heating plants where there are two avenues of waste. The domestic heating plant is extremely inefficient, discharging value up the chimney in the form of unconsumed carbon and valuable by-products that might be obtained by gasification. The unconsumed carbon, in the form of soot, with its accompaniment of sulphur dioxide, unites with water vapor and forms sulphuric acid, destructive to steel, limestone and vegetation. The pall of smoke hides the sun and intercepts the health-giving ultra-violet rays.

Dr. Steinmetz predicted that coal would some day be gasified at the mines and distributed through pipes instead of on wheels. Gasification results in a fuel or fuels (gas and coke) that has a form value superior to that of the coal from whence it was derived and in addition leaves many valuable by-products, such as tar, pitch and oils. Constant research in the treatment of coal is revealing the possibilities of various processes of low temperature carbonization and complete gasification.

The extensive acceptance of gas as a building-heating medium waits on the following elements:

a. Economic pressure due to rising cost of heating fuels that are now cheap in first cost but that cannot be efficiently utilized.

b. Development of cheaper gasification processes and public utility commission and municipal approval of the marketing of the gas resulting therefrom.

c. Development of uses for by-products of gasification.

d. Increasing demand for unpolluted atmosphere.

DISCUSSION

C. G. SEGELER (WRITTEN): While I was reading Major Stark's paper, it occurred to me that many engineers would wonder why the development of gas for house heating had followed such radically different lines from the development of oil for house heating. The entire picture of gas house heating is associated with designed boilers used for gas, while oil burners are almost invariably conversion systems.

There is not time now to discuss the technical reasons why gas conversions have not been as widely adopted as the gas-designed boiler, but essentially the engineers have found that it is not possible to approach the efficiency of a gas boiler by the use of conversion apparatus. In isolated cases, expert engineers could make conversions which would be highly efficient, but the rank and file of plumber or heating contractor who would make such installations is not equipped to do the necessary work which would raise the conversion equipment efficiency to reasonably high levels.

If I may take the time, I would like to point out one or two reasons why conversions tend to be inefficient. First of all, they are usually made with direct flue connection to the stack. This makes so high a draft available that every possible opening in the coal boiler will allow excess air to enter the equipment. The fuel bed resistance to gas flow has been removed when the conversion is made and every bit of the available draft will pull air into the system.

If the draft is broken by the use of a back-draft diverter, and the conversion operated at zero draft as in the case of a regular gas-fired boiler, other problems present themselves. The usual cross section of coal boiler flues is large in relation to the flue surface area. Thus large amounts of heat pass into the stack without ever reaching the effective heating surface of the boiler.

The relation of direct heating surface, that is, surface which would be normally in sight of the radiant effect of a coal bed, to indirect heating surface is relatively high in a coal boiler. According to Major Stark's remarks, the low radiation of a gas flame would render much of this direct heating surface of little value.

Someone may suggest that recent investigations indicate the possibility of a considerably greater radiation effect from blue flames than has previously been supposed. I refer to recent material by Haslam and Hottel printed in Vol. 50, No. 8, of the Transactions of the *A.S.M.E.* They indicate that water vapor and carbon dioxide may have emission bands of sufficient energy content at the infra red end of the spectrum to cause quite some radiation from the non-luminous gas flames over 1500 deg. The percentage of radiant heat depends on the thickness of the gas flame which is radiating, and in the conversion system it would be my personal

estimate that not more than 10 per cent of the heat of the gas flame was directly radiated.

Summarizing the remarks on conversion systems, it may be said that the development of gas house heating has not followed the same lines as the oil burner because the price differential in B.t.u. made it imperative to get as high an efficiency as possible, 75 per cent or better being required by the *A.G.A.* Laboratory for steam and hot water boilers.

Another point which Major Stark has not mentioned, but which may be of interest, is the problem of selecting the proper size gas boiler. It has become accepted practice in the gas industry to use boilers 25 per cent greater in capacity than the total condensing load. This excess is adequate to meet the needs for quick pickup under thermostatic control.

The mention of pickup reminds me of a story about a young married man who was driving his new car, and on meeting a chum was asked, "How is the pickup of your new car?"

"I can't say," was the reply, "because every time that I have been out in it, my wife has been with me."

The gas industry is fortunate in having nation-wide support for the testing program urging the purchase of only such gas equipment as bears the approval seal of the *A.G.A.* Laboratory. The testing program has been devised to coordinate the interests of the consumer, the manufacturer of appliances, the gas industry, as well as the plumbing and heating trades, the Bureau of Standards, the United States Public Health Service and others, to insure safety, durability and economy of all gas appliances. Practically all of the gas companies have pledged themselves to support the program, and it is certain to play a major part in the future of satisfactory gas house heating.

PERRY WEST: I would like to ask if, on p. 351, the analysis of the relative cost of heating with gas and coal is made on a 24-hour basis, and if not, for what number of hours it is made. I would also like to observe in connection with the question of chimney draft, where it is stated on p. 354 that the *American Gas Association* requirements are for zero draft in the furnace, that this, no doubt refers to conditions when the furnace is running under heated condition. For starting up, more draft is required than is sometimes produced under the conditions when the furnace is not running.

In other words, the question of starting the furnace from a cold condition enters into the question of the chimney required.

PROF. J. D. HOFFMAN: I would like to ask Mr. Stark if there is any difficulty presented in the fact that moisture is resulting from the combustion. If there is a difficulty, has that difficulty been overcome in the apparatus in which the combustion takes place?

E. B. LANGENBERG: We have had the same trouble with condensation in old type flues, unlined, where the make and break of a thermostat requires a certain interval with the result that the chimney cools down below a certain temperature. This condensation spreads through the bricks as far as 6 ft. on the side of the

flue, loosening plaster, decorations, etc. I am also looking for information on that point.

H. B. GOMBERS: I would like to ask the gentlemen whether he can give us the rate at which the gas was furnished. In my city the rate is $1.10. On page 351 he mentioned $7.50 per ton for coal. I have just put in 20 tons at $14 a ton.

One of the gentlemen who just finished speaking refers to the plumber. I don't think that plumbers install heating apparatus. This is a heating and ventilating engineers' society, and I think the more you gentlemen get away from that expression, the better for our industry. His answer will immediately be, "We know of hundreds or thousands of plumbers who install apparatus."

Well, I will have to go back to the old riddle, when is a plumber not a plumber? When he installs or does business in some other line than plumbing.

R. V. FROST: In the next to the last paragraph on p. 355 Mr. Stark speaks of Dr. Steinmetz' prediction that coal would some day be gasified at the mines and distributed through pipes instead of on wheels.

In connection with this, this question is being very seriously considered by the anthracite operators and they are finding that they can successfully gasify low grades of anthracite fuel, and that money could really be saved by transmission of gas from the mines to large areas like New York and Philadelphia.

A. A. BLOMFELDT: On p. 356, the closing lines regarding the extensive acceptance of gas as a building-heating medium depends upon certain elements mentioned. I wanted to add a few more points, and three classifications following *d* will be, *e*, the *elimination of labor maintenance cost of operation; f, the demand for efficient automatic control; g, promotion of lower gas heating rates.*

e. Elimination of Labor Maintenance Cost of Operation: Costly service rendered by janitors and firemen, restrictions placed by union regulation of labor, stoppage of heat caused by strikes and walkouts, sympathetic labor difficulties, in other words the operation of the heating plant is dependent upon the availability and disposition of the operators of the heating system. In the large cities we have had costly examples of great suffering by the tenants and owners of apartment buildings and public buildings in addition to the destruction of property, indirectly caused by labor disputes, sometimes of a sympathetic origin.

This is true principally wherein the operation of coal-fired heating plants is involved, requiring union labor for maintenance, whereas gas-fired heating equipment requires no maintenance and is automatically controlled.

f. Demand for Efficient Automatic Control: (100 per cent Availability.) Bodily comfort in heated buildings is today judged by the even and proper maintenance of room air temperature conditions. In coal-fired heating plants it is difficult and a costly investment is necessary in order to maintain automatic temperature regulation of an even and accurate degree.

With gas-fired heating appliances a simple and dependable electric thermostat instantly starts, stops or slows the flow of heat in a most efficient manner. Maintenance, operating and depreciation costs are lowered in the automatic controlled gas-fired heating systems as compared to the wasteful method of regulation of

coal-fired heating plants wherein the fuel supply and consumption is not cut off in a manner comparable with the regulation of gas-fired heating systems.

g. Promotion of Lower Gas Heating Rates: Public opinion has been instrumental in forcing the public utilities to discuss gas service cost. However, the engineering and architectural fraternity can have a greater influence in promoting special low rates for gas heating purposes in districts now supplied by manufactured gas. The reaction of the gas companies in promoting the sale of effective gas heating appliances is an evidence of a spirit of cooperation for the increased sale and use of gas for heating, which eventually will call for further cooperation on the part of the engineer and architect to specify this modern and efficient fuel.

I think these points would be very important in bringing out the advisability of the gas-heating in the proper house-heating.

MR. STARK: Mr. West asked if the analysis giving the comparative cost of heating an assumed building with gas and coal was on a 24-hour basis. I can't say that that is on a 24-hour basis, a 12- and 12-hour basis, or a 10- and 14-hour basis. But it does agree with good, well-founded estimates of the cost of heating. The figure on the cost of heating with gas or the gas consumption is based on the determinations secured by the Consolidated Gas Co., New York, on buildings of a commercial nature where the heating is generally of a periodic character.

I don't think it is safe to attempt to differentiate between 24-hour heating and heating on any other basis in estimating heating costs because there are so many other variables that enter into the making of the estimate, variables that can only be guessed at, so that it really becomes ridiculous to try to differentiate between a constant temperature the day round, and a high temperature in the day time and a lower temperature at night. It is rather a controversial subject, and I don't think anybody really knows the answer to it yet, at least so far as gas is concerned.

Mr. West also asked about the chimney draft on starting up a gas-burning appliance, referring to the test condition of zero draft imposed by the *American Gas Association* laboratory. The requirement necessarily means that an appliance must vent successfully due only to its own chimney effect. Of course, that chimney effect does not instantaneously come up to the maximum figure, but in a gas-burning appliance it attains its maximum figure within a very short time after the fire is lighted, because the conventional gas-burning appliance gets up to its full rating within a very few minutes.

A gas-burning steam boiler is sometimes referred to as a flash boiler. It isn't quite that, but a good gas-burning boiler will be making steam and will, therefore, have a chimney temperature sufficient to vent very well within, say, 8 minutes, from a cold boiler.

Mr. Segeler presented some things that I welcomed with open arms, figuratively speaking, because he said some things that I wouldn't dare say without being accused of trying to sell something.

I want to emphasize again the point in my paper that Mr. Segeler emphasized when he brought out the fact that it is justifiable to try to use a higher degree of accuracy in estimating what we call the starting and piping loads on gas-burning appliances, because we start with an absolutely known and almost invariable quantity, that is, the rating of the appliance.

Professor Hoffman and Mr. Langenberg—I think I can treat their questions together—spoke of the difficulty due to moisture in the products of combustion. That is a thing that I have touched on briefly in the paper where I try to bring out the fact that we might design our appliances to operate considerably more efficiently than they do now, but that it would be at the expense of considerable difficulty in operation. The thing those two men mentioned is the difficulty in operation which we would encounter if we tried to increase the efficiency of our appliances by condensing the flue gases. Even then, sacrificing the 10 per cent we might gain, we have the condition Mr. Langenberg brought out. There is generally a cure for such things. Naturally the best cure for condensation seeping through the chimney is an improved chimney construction.

When a gas-burning appliance is used with an extremely old and porous chimney in which the mortar has deteriorated, perhaps an unlined chimney, condensation may seep through. The surest preventive of condensation trouble with gas-burning appliances is a good chimney draft, because the good chimney draft pulls more air in through the so-called draft diverter that Mr. Segeler mentioned, and mixes it with the flue gases escaping up the chimney. The more air that gets into the flue gas, the lower the condensation temperature becomes, strange as it might seem.

The surest relief for chimney condensation is a good chimney draft to start with, and a plentiful supply of air to get into the chimney to dilute the products of combustion and keep them moving faster up the chimney, wiping the sides cleaner, and also lowering the dew point temperature of the flue gases.

One gentleman, in asking about the analysis on p. 351, inquired what gas rate was stated. Seventy-five cents a thousand feet was the rate used. He said in his city the gas rate is $1.10. Not a great deal of heating is done on $1.10 gas. He also said that he just put in some coal that I believe cost $14 a ton. He might seriously consider using gas. It would not cost a great deal more.

Mr. Frost referred to Dr. Steinmetz' prediction as quoted on page 355, and there is nothing there to which I can reply.

Mr. Blomfeldt added some elements to the enumeration of the elements controlling the more extensive use of gas as a heating medium, which I have given on page 356. They are all good and a worthy addition to this.

MR. GOMBERS: I had an investigation made and found that it would cost me about $640.00 to have a gas heating boiler installed; and it would cost about $840.00 a year for the gas consumed in the boiler to take care of 800 ft. of radiation needed to heat my house of 15 rooms which includes 2 bath rooms. That is why I don't propose to attempt to heat my house with gas at this time.

H. M. HART: There was an interesting question brought up, that is, the percentage to be added for the starting load, and I want to ask how you arrive at the 20 per cent for starting the load. Also justifying the figures on coal and gas, $0.75 is the heating rate for gas in Chicago, 550 B.t.u. gas, and $7.50 is about the average rate for Pocahontas mine run coal, which is probably used more than any other kind of coal in Chicago for that purpose.

W. E. STARK: Mr. Hart asked the source of the 25 per cent allowance that was

really brought out in Mr. Segeler's discussion. I presume the figure was determined on the basis of experience. People found out when they allowed enough for starting on a job of a certain character that 25 per cent for starting was large enough. Of course, starting and piping load is a load that is extremely difficult to evaluate, and it is simply determined by experience so far as I can see.

H. B. JOHNS: The American Gas Association Committee on Approval Requirements for central house heating appliances in its 1928 report recommends the use of selection factors similar to those used in Chicago. These factors begin with an addition of 56 per cent to the equivalent steam radiation and drop to 40 per cent at 4000 sq. ft. and over. I believe these can be taken as the *American Gas Association's* recommendation in the matter.

No. 801

METHOD OF CALCULATING COST OF GAS HEATING

By A. E. Stacey[1] (*Member*) and W. B. Thornton (*Non-Member*)

Newark, N. J.

DUE to the increasing use of gas as a fuel for heating, the thermal engineer is interested at the present time in methods for determining the efficiency of gas burning equipment and also a practical and easy method to approximate the yearly consumption of gas for any installation.

In order to determine the efficiency of a gas burning apparatus, it is customary to make an analysis of the flue gases by the use of an Orsat machine. From this analysis a fairly exact determination of heat losses can be made. (See Appendix 1.) The following approximate method for obtaining this information is offered.

From a study of the chemical analysis of different gases, it was found that the amount of moisture in gases resulting from combustion varied with the percentage of excess air introduced into the combustion chamber. This relationship presents an easy method to determine the amount of heat loss in flue gases.

Fig. 1 gives curves for the different types of gases, showing the relationship between the percentage of excess air and the dew-point temperature of the flue gases. For example, Curve *A* is for coke oven gas or retort coal gas. With 100 per cent excess air, the dew point of the flue gases would be 110½ deg. fahr. This is correct within 3 or 4 per cent. Figs. 2 and 3 give the relationship between the flue gas, dry-bulb temperature and the amount of heat lost in the effluent gases with different percentages of excess air. For example, if there is 30 per cent excess air and a dry-bulb temperature of 350 deg. fahr. in the flue gases, there would be a loss of 17 per cent. It is interesting to note the effect of excess air on the efficiency of the equipment. For example, if instead of 30 per cent excess air, there was only 15 per cent with the same temperature of flue gases, the loss up the stack would be 16.3 per cent or a decrease of 0.7 per cent. If, however, the excess air increased to 60 per cent, the losses would be 18.5 per cent. The effect of the flue temperature on the losses is also of great importance. By referring again to Fig. 2, it is shown that by an increase of 50 deg. fahr. in the flue temperature, there is 1.2 per cent increase in loss up the stack and by lowering the flue temperature 50 deg. fahr., there is an increase in efficiency of 1.2 per cent.

By the use of the two curves, the stack loss is easily determined. While the flue loss, no doubt, is in most cases of the greatest importance, there is loss by

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Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, West Baden, Ind., June, 1928.

radiation in connection with every gas burning appliance. In different types of appliances, this varies from 3 per cent to 10 per cent. In obtaining the overall efficiencies, the radiation loss must be added to the flue losses. In a great many cases, the heat given off by the appliance through radiation is not lost, as it assists

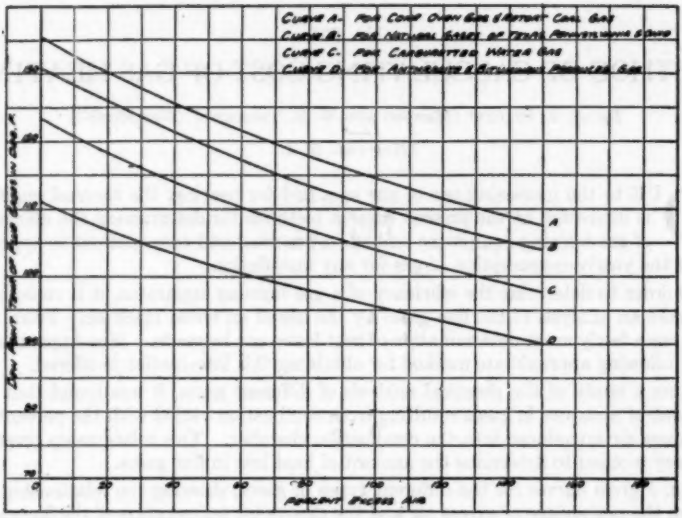

FIG. 1. RELATION BETWEEN DEW POINT OF FLUE GASES AND PER CENT EXCESS AIR (AIR FOR COMBUSTION CONSIDERED PERFECTLY DRY)

in heating up the basement or the room where the appliance is located. Efficiencies of different types of gas burning equipment, as found in practice, are shown in Table 1.

TABLE 1. USUAL EFFICIENCY RANGES* FOR GAS BURNING HEATING APPLIANCES

Type of Appliance	Heat Transfer Efficiency	Gross Efficiency
Low pressure steam boilers	80% to 85%	70% to 82%
High pressure steam boilers	78% to 83%	68% to 80%
Hot water boilers	80% to 85%	70% to 82%
Natural draft furnaces	75% to 85%	65% to 80%
Forced draft furnaces	80% to 91%	72% to 89%

* Table applies to appliances specially designed for burning gas. It cannot be used for average results in conversion jobs.

$$\text{Heat Transfer Efficiency} = \frac{\text{Gross Heat Input} - \text{Flue Loss}}{\text{Gross Heat Input}}$$

$$\text{Gross Efficiency} = \frac{\text{Gross Heat Input} - (\text{Flue Loss} + \text{Boiler Radiation Loss})}{\text{Gross Heat Input}}$$

The degree-day as used by the *American Gas Association* offers a very convenient method for calculating the total yearly consumption of gas for any installation. This is based on the number of degrees below 65 deg. fahr. in any heating season.

In the *American Gas Association's* bulletin on House Heating, there is published on pages 11, 12 and 14, the degree-days for a large number of cities. This information is also available in the A.S.H.&V.E. GUIDE, 1928.

The tabulation given shows a list of cities with the corresponding degree-days.

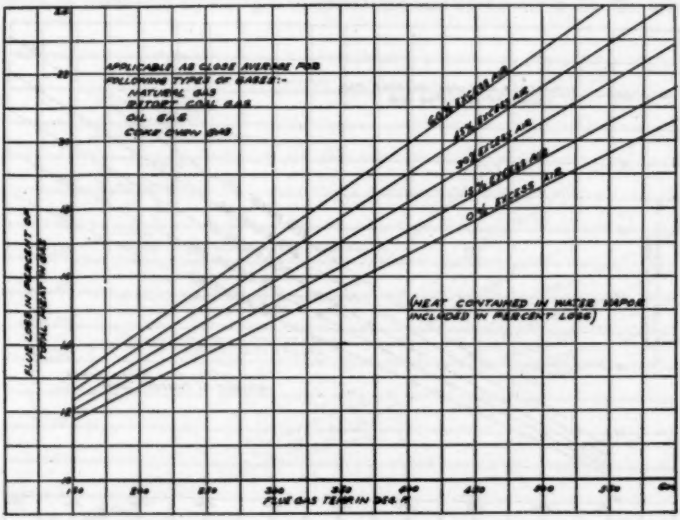
APPLICABLE AS CLOSE AVERAGE FOR FOLLOWING TYPES OF GASES:-
NATURAL GAS
RETORT COAL GAS
OIL GAS
COKE OVEN GAS
60% EXCESS AIR
40% EXCESS AIR
30% EXCESS AIR
15% EXCESS AIR
0% EXCESS AIR
(HEAT CONTAINED IN WATER VAPOR INCLUDED IN PERCENT LOSS)
FLUE LOSS IN PERCENT OF TOTAL HEAT IN GAS
FLUE GAS TEMP IN DEG. F.

FIG. 2. RELATION OF LOSS OF HEAT IN FLUE GASES TO FLUE-GAS TEMPERATURES

These were selected to show the heating requirements of different sections of the country.

City	Degree-Days	City	Degree-Days
New York, N. Y.	5303	Detroit, Mich.	6202
Boston, Mass.	6055	Chicago, Ill.	6007
Buffalo, N. Y.	6750	Minneapolis, Minn.	7953
Cleveland, Ohio	6096	Kansas City, Mo.	5302
Cincinnati, Ohio	5302	Tulsa, Okla.	3497
Philadelphia, Pa.	4950	Dallas, Tex.	2455
Charlotte, N. C.	3153	San Antonio, Tex.	1362
Atlanta, Ga.	2880	Denver, Colo.	5880
Jacksonville, Fla.	1080	Salt Lake City, Utah	5358
New Orleans, La.	1044	Los Angeles, Calif.	1517
St. Louis, Mo.	4583	San Francisco, Calif.	3450
Indianapolis, Ind.	5331	Seattle, Wash.	5136

By referring to Fig. 4, which gives the relationship between the degree-days and the gas consumption in thousands of cubic feet per year for different types of gases, it is possible to estimate easily the yearly consumption of gas for different installations. This relationship is similar to that shown in the A.S.H.&V.E. GUIDE, 1928, on pages 238 and 239, with the exception that that chart is based on one efficiency only for the gas burning equipment. With the chart now presented, based on 100 per cent efficiency, the result must be divided by the efficiency of the apparatus which is being used.

The ranges of efficiencies for different types of equipment are given in Table 1

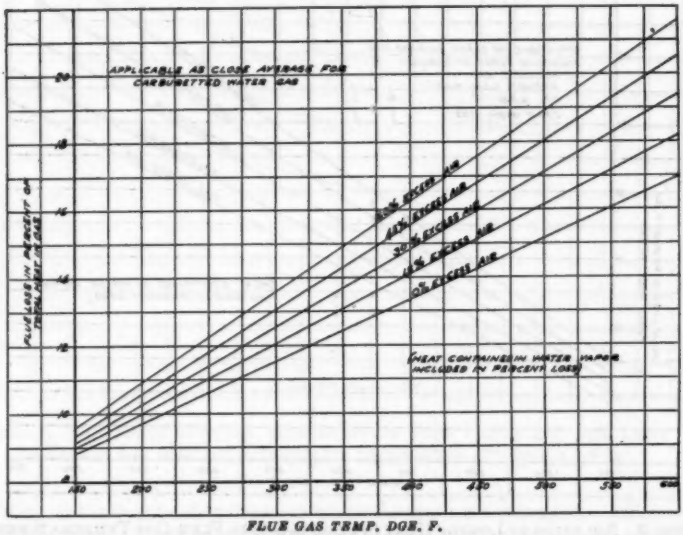
APPLICABLE AS CLOSE AVERAGE FOR CARBURETTED WATER GAS
FLUE LOSS IN PERCENT OF TOTAL HEAT IN GAS
HEAT CONTAINED IN WATER VAPOR INCLUDED IN PERCENT LOSS
FLUE GAS TEMP. DGR. F.

FIG. 3. RELATION OF LOSS OF HEAT IN FLUE GASES TO FLUE-GAS TEMPERATURES

and by the use of the dew-point method of determining excess air and stack losses, the efficiency of the apparatus in question is easily determined as shown. This chart gives the yearly consumption in thousands of cubic feet of gas based on B.t.u. estimates, using the standard A.S.H.&V.E. method of determining heat losses from buildings. In case these losses have been determined directly in square feet of steam radiation or square feet of hot-water radiation, the simple formula given can be used to determine the yearly gas consumption.

For example, New York has 5300 degree-days and the gas that is burned in New York has a heating quality of 530 B.t.u. per cu. ft. The value of Q would then be 34.5. By referring to formula (*a*) for steam radiation, $G = \frac{0.024\ RQ}{E}$ and solving with the value of R equal to 1 sq. ft. of radiation, the consumption of gas

per sq. ft. of steam radiation if E = 85 per cent is 0.974. If a hot-water system is being considered, equation (B) would be used and (Q) would be obtained in the same manner. In case the installation under question is a warm-air system, the equation (C) would be used.

Conclusions

First: A simple method has been presented for the approximate determination of excess air in flue gases.

Second: Charts have been provided which demonstrate the variation in efficiencies as influenced by flue-gas temperatures and excess air in the flue gases.

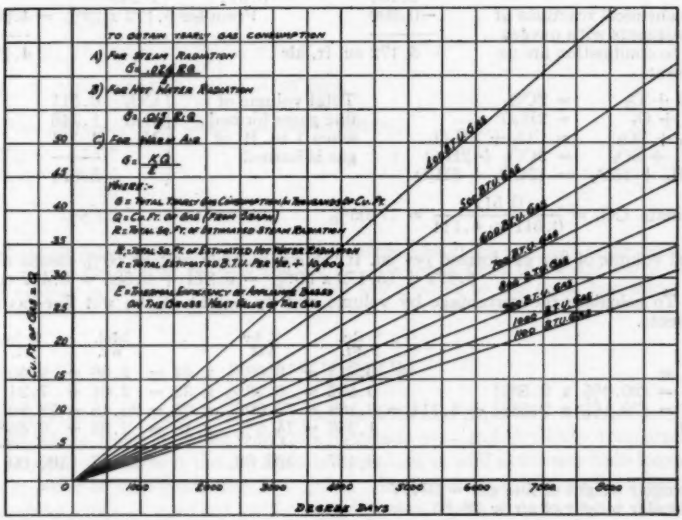

FIG. 4. RELATION OF HEAT REQUIREMENTS AND YEARLY GAS CONSUMPTION

Third: Charts are included which show the relationship between the degree-days and the yearly gas consumption for different types of systems.

Fourth: A method is offered for the determination of yearly gas consumption based on the excess air content of flue gases and on the efficiency charts.

APPENDIX

A sample calculation of flue losses for coke oven gas.

Assume a flue temperature of 300 deg. fahr. and excess air quantity of 50 per cent. The gas as outlined has a gross heat value of 588 B.t.u. per cu. ft.

	% by Vol.		Cu. Ft. of Air Required	Products of Combustion in Cubic Feet for 0% Excess Air		
				CO_2	H_2O	N_2
CO	= 6.3 %	x 0.5 x 4.77 =	0.151	0.063		
CO_2	= 1.8 %	x		0.018		
H_2	= 53.0 %	x 0.5 x 4.77 =	1.265		0.53	
N_2	= 3.4 %	x				0.034
O_2	= 0.20%	x 1.0 x 4.77 =	(−0.0095)			
CH_4	= 31.6 %	x 2.0 x 4.77 =	3.020	0.316	0.632	
C_2H_4	= 2.7 %	x 3.0 x 4.77 =	0.387	0.054	0.054	
C_4H_8	= 1.0 %	x 7.5 x 4.77 =	0.358	0.060	0.030	
			5.181	0.511	1.246	
The chemical reactions of constituents with oxygen due to combustion are as follows:			−0.009	From air 5.172 x 79% =		4.08
			5.172 cu. ft. air			4.114

$2CO + O_2 = 2CO_2$
$2H_2 + O_2 = 2H_2O$
$CH_4 + 2O_2 = CO_2 + 2H_2O$
$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$
$2C_4H_8 + 15O_2 = 12CO_2 + 6H_2O$

Total volume of flue gases formed when 1 cu. ft. of gas is burned

CO_2	0.511
H_2O	1.246
N_2	4.114
	5.871

Ultimate $CO_2 = \frac{0.511}{0.511 + 4.114} = 11.05\%$

Total volume of flue gas formed per cu. ft. of combustible and at 50% excess air = 5.871 + (5.172 x 50%) = 5.871 + 2.586 = 8.457 cu. ft.

To calculate the percentage by volume and by weight of the wet flue-gas constituents.

	Cu. Ft.	% by Vol.		Mol. Wt.	% by Wt.
CO_2 =	0.511 =	6.03%	x 44 =	2.66 =	9.60%
O_2 = (20.9% x 2.586)	0.532 =	6.28%	x 32 =	2.01 =	7.24%
N_2 = (79.1% x 2.586) + 4.114 =	6.168 =	73.00%	x 28 =	20.45 =	73.70%
H_2O	1.246 =	14.6%	x 18 =	2.65 =	9.46%
	8.457	100.00		27.77	100.00

Molecular weight of flue gas = 27.77
Molecular weight of air = 28.85
Weight per cu. ft. of dry air at 60 deg. fahr. D. B. = 0.0764

Total weight of flue gases = $\frac{0.0764 \times 8.457 \times 27.77}{28.85} = 0.622$ lb.

To determine the amount of heat existing in flue-gas constituents above 60 deg. fahr.

CO_2 = 9.6% x 0.622 = 0.0597 lb.	x (300 deg. − 60 deg.) 0.210 =	3.01	B.t.u.
O_2 = 7.24% x 0.622 = 0.0450 lb.	x (300 deg. − 60 deg.) 0.217 =	2.35	B.t.u.
N_2 = 73.7% x 0.622 = 0.4590 lb.	x (300 deg. − 60 deg.) 0.247 =	27.20	B.t.u.
H_2O = 9.46% x 0.622 = 0.0589 lb.	x (300 deg. − 60 deg.) 0.423 =	5.97	B.t.u.
0.6220 lb.	Total sensible heat =	38.53	B.t.u.

To the sensible heat must be added the latent heat of evaporation of the water existing in the flue gases. To do this, determine the dew point of the flue gas as follows:
% by weight of water in flue gases = 9.46
Total weight of flue gases = 0.622 lb.

Then the number of grains per lb. of flue gas = $\frac{0.622 \times 9.46\% \times 7000}{0.622} = 672$ grs. per lb.

672 grains per lb. correspond to a dew point of 124.2 deg. fahr.
The average temperature of evaporation will be the mean average temperature between 60 deg. fahr. and $124^1/_2$ deg. fahr. or $92^1/_4$ deg. fahr.
Heat of evaporation at 92.25 deg. fahr. = 1040 B.t.u./lb.
0.0589 lb. H_2O x 1040 = 61.3 B.t.u. = Latent heat loss
Sensible heat loss = 38.53 B.t.u.
Latent heat loss = 61.30 B.t.u.

Total heat loss = 99.83 B.t.u.

Per cent of gross heat loss in flue gases = $\frac{99.83 \times 100}{588} = 16.95\%$

The volume of the dry gases for the preceding analysis is as follows:

$$\% CO_2 = \frac{11.05\%}{1.5\%} = 7.37\%$$

$$\% O_2 = 20.9 - 20.9 \frac{(7.37)}{(11.05)} = 6.94\%$$

$$\% N_2 = 100 - (7.37 + 6.94) = 85.69\%$$

Flue gas analysis by Orsat machine would be:

$$\% CO_2 = 7.37$$
$$\% O_2 = 6.94$$
$$\% N_2 = 85.69$$
$$100.00$$

In these calculations, the air required for combustion was assumed to be perfectly dry. This is not usually the case and for exact computations the water vapor originally existing in the air should be considered and credited to the stack loss under the item of sensible heat loss in H_2O.

DISCUSSION

W. H. CARRIER: One point in connection with this paper which I wish to make is that where there is much variation between wet- and dry-bulb temperatures it is necessary to observe the dry-bulb temperature as well as the wet-bulb temperature in order to determine the dew point. If the air is substantially saturated, as in some types of gas-fired air heating furnaces, there is no material difference between the wet-bulb temperature and the dew point. However, in the case of a steam boiler where the gas temperatures must necessarily be above the steam temperature, there is necessarily quite a difference between the dry-bulb temperature and the wet-bulb temperature so that the dew point must be determined by observing both temperatures.

It is true, as pointed out in the paper, that the dew point bears a definite relation to the per cent of excess air with little variation for different kinds of gas burned. However, if the per cent of excess air is determined by means of the dew point, the amount of heat lost per cubic foot or per lb. of flue gas is determined solely by the wet-bulb temperature as this temperature is a direct measure of the heat content of the gas.

The other point I wish to make applies perhaps more specifically to the preceding discussion. There is an additional loss up the stack due to the fact that you have a draught breaker which draws in a portion of air direct from the furnace room in

the basement. This is a stack loss that does not enter into the efficiency of the furnace itself but rather into the efficiency of the entire heating system.

Radiation from the furnace may, as pointed out in this paper, be available in heating the house if it is not in excess; that is if it merely keeps the space where the boiler is located up to normal temperature, it is of no distinct advantage. However, it becomes a loss if the radiation is in excess of this amount.

Certain inefficiencies due to stack losses must be provided for, for that reason it is desirable to introduce excess heat and excess air to avoid condensation in the chimney and connecting flues. A better way perhaps would be to build chimney flues for gas burning of considerably smaller size than standard for coal and to build such chimney flues with glazed tile with bell joints facing upward and sealed with some type of plastic cement. Condensation would then be of no detriment to the rest of the chimney structure and considerably greater economy could be realized in gas burning.

HARRY HART: I would like to ask if there is a disintegrating effect on mortar used in the joints of tile from the gases from a gas-fired boiler. I ask this question because some years ago we used to have natural gas in Chicago of approximately 1000 B.t.u. at fifty cents a thousand, and a great many applications were made to coal-fired boilers with gas burners.

Then when this natural gas gave out and the price for artificial gas got high they had to go back to coal. Invariably they found that the chimneys were in very bad condition, had to be practically reconstructed; the mortar had all been eaten out of the joints.

I would like to know if there is any information on that point available.

W. E. STARK: I might try to answer Mr. Hart's question. If there is any disintegrating effect of the moisture in the flue gas on the mortar, I believe it depends on the constituents of the gas more than anything else. That disintegrating effect is probably getting less as the years go by, and as the art of making gas becomes farther advanced.

In some localities there is quite a little bit of sulphur in the gas; that is, manufactured gas. In other places they desulphurize the gas more effectively, and there is not so much dilute sulphuric gas formed in the moist products of combustion. So I think if there is any disintegrating effect on the mortar from combustion, it is getting less and less as the years go on.

PROF. J. D. HOFFMAN: Confirming the statement made by Mr. Hart, Chicago had for a long time been supplied with natural gas from the same line that passed through Lafayette. We had the same experience in our city. When we had to leave gas and go back to coal, practically all the old chimneys were out of order and had to be relined or reconstructed. I rather think the trouble was the sulphur content of the gas.

MR. HART: One more point that I think we ought to begin to talk about: The tendency is for lower B.t.u. gas, but there seems to be a resistance to this trend by the public utilities commission, so I think that we ought to have more light on the subject. Now, do we know at what point in B.t.u. value gas for fuel is the cheap-

est to manufacture for distribution for fuel heating? If we do know, I think we ought to go on record so that that information can be broadcast, and help influence these people to accept lower B.t.u. gas.

C. G. SEGELER: I think Mr. Hart has brought up a subject upon which there is no more controversial point. I doubt whether such a thing as the most economical B.t.u. value could be determined. The gas suitable for any community depends on many factors. The best place to think that over is in Illinois, in your territory, because there you have local Illinois coals from which a low B.t.u. gas could be made, but the present regulations call for coals from more distant sources. Gas-making is a complicated chemical process and I think the B.t.u. regulation is a subject which for the time being should not be touched upon. I do not believe any one knows the answer, and I think that from the utilization point of view the gas companies are themselves seeking the best answer right along.

The fuel user, the consumer, is not greatly affected by the variation in B.t.u. value because for his given community the appliances are set to operate satisfactorily.

I think perhaps Mr. Conner of the Gas Testing Laboratory may be here, or coming, and will tell you of the tests run from gas of 400 B.t.u. to high gravity, 1100 B.t.u. natural gas, and the appliances have to operate perfectly satisfactorily over the entire range.

That is a controversial subject which I would suggest this organization not attempt to go into at this time.

C. G. BINDER: On p. 365 there is a table giving the degree-days. May I ask if that is an average for a number of years or for one year?

L. L. LEWIS: I cannot tell you.

W. B. CRAWFORD: I cannot answer some of these highly technical questions, but I have made a practical experiment of heating with gas in Chicago, in a six-room flat, having approximately 500 sq. ft. of direct radiation.

The Gas Co. told me when I investigated the buying of a Gas Boiler, that it would cost me roughly about 50 cents per sq. ft. of radiation per season. In this experiment I took a round Arco 25-in. boiler with certain copper coil, burners, etc. I employed a No. 21 semi-Bunsen Barber burner. Originally I put in two of these burners and set them at about 45 deg. fahr. in relation to the fire-box of the boiler.

Still later I had a better idea and I had a copper coil built connected through the water back opening to the front circuit and through the bottom water back opening to a tapped opening in the water leg of the boiler. I now installed one of the No. 21 burners and located this burner above the grate but approximately 12 in. below the copper coil. I took the ash door off entirely, closed the check draft entirely with exception of the usual leakage around the check draft which is sufficient to carry off the fumes. When the burner was on full blast there was a very low temperature on the smoke uptake. Later I installed wrought iron plates approximately 5 in. x 8 in. x $\frac{1}{4}$ in. thick and placed same over the small flue passages in the boiler and made large plates with adjusting screws to be placed

over the large flue opening of the boiler and thereby reduced the flue area to approximately 20 per cent the original area. The boiler was well insulated on the outside.

The cost of gas for the last heating season averaged $1.00 per day or roughly 50 cents per sq. ft., which I understand would have been the approximate cost using a gas boiler. I operate the gas valve from a thermostat located in the living room and the temperature throughout the flat was approximately 70 deg. fahr. The average cost was taken through a period covering only the cold months. If I had started the plant and operated over a little longer period, the average cost would have been less.

The gas bills are as follows:

	2nd Apt.	1st Apt.
September 30 to November 1	$10.57	$13.42
November 1 to December 1	30.82	22.57
December 1 to January 3	55.87	39.67
January 3 to January 31	46.57	33.67
January 31 to March 2	49.27	35.47
March 2 to March 30	33.07	19.12
March 30 to May 2	24.97	23.62
May 30 to July 1	.79	

Now, with all this discussion, I am curious to know what I would have saved had I put in a gas boiler specifically designed for the purpose.

F. D. MENSING: There are one or two remarks that have not been explicitly answered. Mr. Hart asked about the effect of the flue gases from gas on chimney construction. A piece of galvanized pipe will recoat in about one month. Therefore, I suspect sulphuric acid. Sulphuric acid is bad on any mortar about which I know.

To Mr. Binder's question as to the period, I think that is based on an eleven-year period from compilations that we have made in the office.

P. E. FANSLER: I do not know what these figures are based on, but I guess on all the records of the government which run from 50 to 100 years; they vary in different cities, and the average that the government uses is for the period of time that the Bureau station has been in existence.

A. A. BLOMFELDT: Supplementing Mr. Carrier's remarks on the flue gas losses, I have in mind a factory building where we installed fifty-four gas-fired unit heaters; the building space was approximately four million cubic feet and the losses through the stacks or the vents were calculated ten thousand cubic feet of air per minute. Whereas this would seem a serious heat loss, in fact it turned out to be an asset to the ventilating in getting air changes of about six times an hour in the plant which was rather an interesting development because it is an auxiliary gravity ventilating system in fact.

MR. SEGELER: I would like to ask a question of the gentleman who spoke of the converted system. That interested me particularly. He had a single unit thermostat, I understood, in a flat house.

MR. CRAWFORD: In the dining room.

MR. SEGELER: How did you know that you did not have it in a room so regulated with the rest of the house, that while you had 70, everybody else had 68? Even a degree of difference in temperature which still might not affect the comfort of the household might make quite a difference in the total fuel bill.

I believe that the gas-designed boiler would have been calculated and the original estimates made in accordance with 70 deg. fahr. throughout, or whatever specified temperature it was throughout the entire building. I do not believe that you have taken care of—although you may have—the question of where the thermostat was located.

MR. CRAWFORD: I selected the dining room with a north exposure for locating the thermostat and possibly the front of the flat or the rear of the flat might be a degree or so cooler.

The Gas Co. in Chicago was so interested in this little experiment that they sent an engineer out to make a sketch of the scheme and asked me to save my gas bills for the past heating season and I understand they are coming out a little later to check up last year's performance. I think that the copper coil added greatly to the efficiency of the entire apparatus and I do not think the temperature varied more than a couple degrees from one end of the flat to the other.

There are a number of gas heating plants in Oak Park and River Forest having approximately the same amount of radiation where the cost has been practically double the cost I was able to secure.

No. 807

HEATING INDUSTRIAL BUILDINGS WITH WARM AIR

By J. C. MILES,[1] CLEVELAND, OHIO

MEMBER

THE practice of using direct fired fan-furnace heating systems for warming certain types of industrial buildings presents many attractive features which the heating engineer, architect and building owner may find it profitable to investigate. Such systems are relatively simple and, therefore, economical in first cost and operation, are flexible and readily responsive to the heating demands, provide effective air circulation within the building, overcoming stratification and high ceiling temperatures and require small maintenance expense.

These systems are easily designed and reliable data are now available as to the efficiencies and heat transmission factors of the heaters when operating on various fuels. Data on fans, motors and design of the duct system, are the same as for similar systems using steam or water-heated surfaces, so that any heating and ventilating engineer can intelligently handle such layouts and installations.

The Woodward Garage Building, in Cleveland, O., is a specific example in economy—in maintenance—and in fuel consumption. The building was built as a storage garage. The construction is of the one-story type, with what is known as the Chicago or curved truss roof, Fig. 1. The walls are built of common brick, exposed on all sides. There are three large doors used for the entrance and exit of automobiles, and sufficient glass area to furnish adequate light. In addition to the glass area in the walls, there is a monitor with some glass exposure, which monitor is built of single board construction. There is also a very small skylight over one corner of the building where some little repair work is done.

The contents of the building is 375,000 cu. ft.; the height is approximately 23 ft.; the roof is built up of tar-paper and gravel on 1-in. tongue and grooved board. The windows are single glass. The doors are 2-in. tongue and grooved lumber; the floor is 4-in. concrete on cinders. Calculations made for this building were 4284 sq. ft. of 18-in. common brick walls; 3339 sq. ft. 12-in. common brick wall; 1698 sq. ft. of single 1-in. tongue and grooved board walls on the monitors; 165

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[1] Vice-President, The Warm Air Furnace Co., Cleveland, Ohio.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.

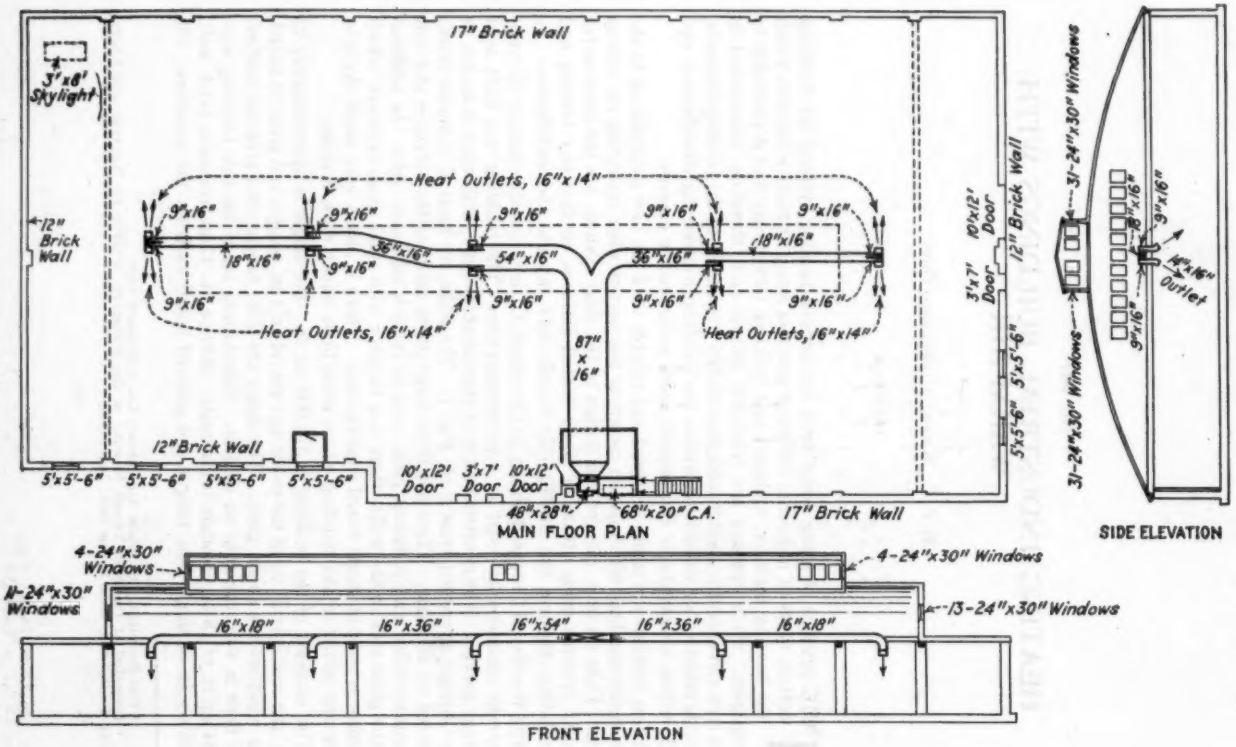

FIG. 1. PLAN OF CLEVELAND STORAGE GARAGE SHOWING AIR DISTRIBUTING SYSTEM

sq. ft. of glass for side-walls and 494 sq. ft. of glass in monitor which includes a small amount of glass in a skylight; 402 sq. ft. of door area; 18,000 sq. ft. of roof; and 16,600 sq. ft. of floor area. The outside measurement of the building is 182 x

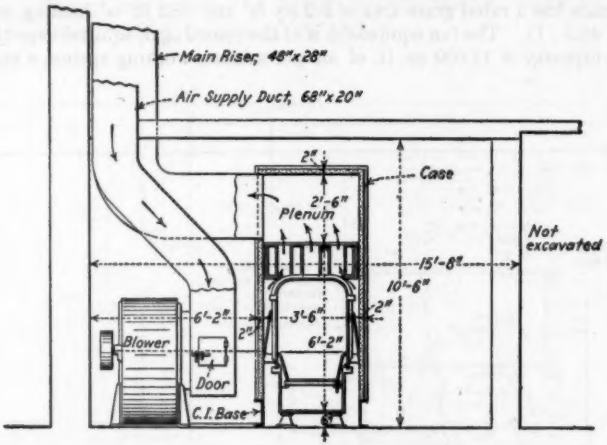

FIG. 2. CAST-IRON FURNACE WITH FAN EQUIPMENT

91 ft. The coefficient of heat losses used were taken from the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS standards and are as follows:

Brick wall (18 in.)	0.218
Brick wall (12 in.)	0.278
Roof	0.485
Monitor wall	0.35
Monitor skylight and window glass	1.13
Doors	0.382
Floor	0.490
Infiltration	0.018

The calculation for infiltration was based upon an estimated opening and closing of the doors, as well as leakage around the windows, doors and other possible inlets. The amount of this was estimated to be one complete air change, per hour, as an average. It was understood, however, that during the morning and evening period when the cars were leaving or returning to the garage, the inlet of air would, in all probability, many times exceed one change per hour.

The desired temperature in this building was originally 50 deg. fahr., but in view of the fact that after the heating contract was arranged, a change was made in the roof construction from a flat roof to the Chicago type roof, the owners were amenable to a 40 deg. temperature. Therefore, this calculation is made on the basis of 40 deg. temperature in zero weather. The total estimated heat

loss per hour in zero weather, using the above constants and 40 deg. temperature difference, was 754,300 B.t.u. per hour (approximate).

The heating system consists of one horizontal type cast-iron furnace, as shown in Fig. 2. The manufacturer's rating on this furnace is 850,000 B.t.u. per hour; the furnace has a rated grate area of 8.2 sq. ft. and 382 ft. of heating surface (a ratio of 46.5 : 1). The fan equipment is of the centrifugal, squirrel-cage type, with a rated capacity of 13,000 cu. ft. of air per minute, working against a static pres-

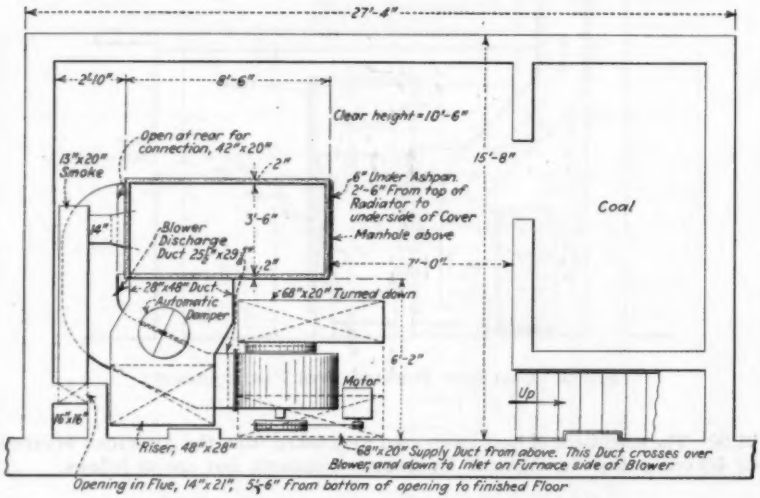

FIG. 3. DETAILS OF AIR SUPPLY AND RECIRCULATION

sure resistance equal to $^3/_4$-in. water gage. The air is taken from the floor and recirculated as indicated in Fig. 3.

There is an automatic by-pass louver damper in the cold air duct between the fan and furnace, which is forced to close by the pressure developed when the fan is in operation, but is balanced so that it will automatically fall open when the fan is shut off. This damper allows for air supply in addition to what is passed through the fan. This by-pass opening serves as a protection to the furnace when the fan is not running, as well as to furnish a small amount of heat through gravity circulation.

The system of heat distribution is by over-head warm air ducts, with a total of ten outlets, distributed at various points down through the center of the building as shown in Fig. 1. These outlets are directed at an angle of approximately 45 deg., so that the outlet velocity, calculated at 1000 ft. per minute, may deliver the air at the floor.

Sufficient tests were made to indicate a possible combustion rate of 15 lb. of fuel per hour.

A laboratory test was made by the late John R. Allen, on a furnace of the same make and design, but of smaller size, which would indicate a safe assumption of an over-all efficiency of 60 per cent.

The temperature difference shown in test chart, Fig. 4, indicates a temperature rise of 60 deg. fahr., hence the possible heating capacity would be 780,000 x 60 x 0.24 x 0.78 = 890,000 B.t.u. (approximate).

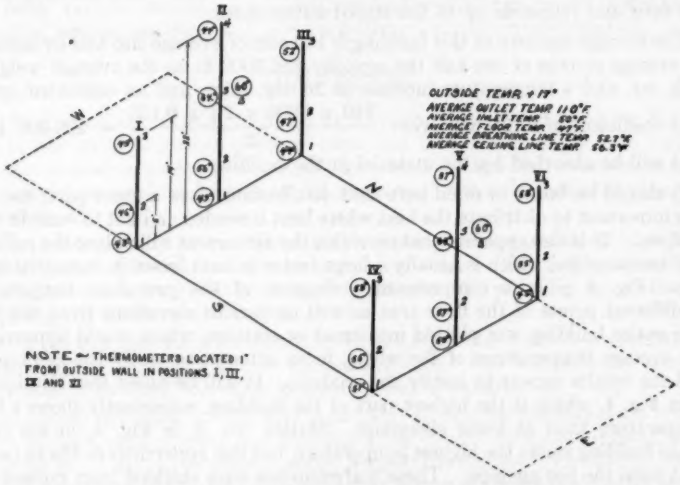
OUTSIDE TEMP. 4 19°
AVERAGE OUTLET TEMP 110°F
AVERAGE INLET TEMP 50°F.
AVERAGE FLOOR TEMP 47°F.
AVERAGE BREATHING LINE TEMP 52.7°F
AVERAGE CEILING LINE TEMP 66.3°F
NOTE ~ THERMOMETERS LOCATED 1' FROM OUTSIDE WALL IN POSITIONS I, III, IX AND XI

FIG. 4. TEMPERATURE CHART SHOWING RANGE AT SEVERAL POINTS IN BUILDING

Season's Estimated Heat Loss

Based on the geographic location of this building, and using the U. S. Weather Bureau's average temperature estimate during the heating period of this observation, it was found that the total heat loss to maintain the temperature of 40 deg. fahr. for a full season of 182 days or 4368 hours, should be in accordance with our calculation—660,000,000 B.t.u. The heat loss per hour per degree difference in temperature was calculated at 18,856 B.t.u. and the actual loss for the season of $^1/_3$ of the maximum indicates 18,856 x 4368 x 40 x 0.20 = 560,000,000 B.t.u.

Since the ground temperature beneath the floor is 50 deg. there is a possible source of heat supply which may be estimated at 5 deg. fahr. temperature difference.

Then with 660,000,000 − (16,600 x 0.49 x 5 x 4368) = 482,000,000 B.t.u. loss per season calculated, it was found upon investigation of the fuel used for the season, that the 18 tons of run-of-mine Pocahontas and a small amount of Pittsburgh bituminous coal were burned. By adding 10 per cent for wood and calculating the total heat value, using 14,000 B.t.u. per lb., a total of 555,000,000 B.t.u. was obtained thus: 18 x 2000 x 14,000 x 0.10 = 555,000,000. Since the burned

fuel value is 555,000,000 B.t.u. and the calculated heat loss is 482,000,000 B.t.u. the efficiency is: $100 \times \frac{482,000,000}{555,000,000} = 87$ per cent.

This fan blast, or forced air system, consisted of an over-head duct at about 15 ft. from the floor, with branches leading down to a level of approximately 12 ft. from the floor; the outlets of these branches are directed so that the current of incoming warm air comes in direct contact with the automobiles stored or strikes the floor and rebounds up to the stored automobiles.

The storage capacity of this building is 140 cars of average size and by assuming an average storage of one-half the capacity and 3000 lb. as the average weight of each car, and a temperature increase of 20 deg. fahr., and an estimated specific heat coefficient of 0.125, we have: $\frac{140 \times 3000 \times 20 \times 0.125}{2} = 525,000$ B.t.u. that will be absorbed by the material in the building.

It should be borne in mind here that distribution plays a great part, and that it is important to distribute the heat where heat is needed and not to outside walls, roof, etc. It is also apparent that reversing the air current will reduce the ceiling or roof temperature, which is usually a large factor in heat losses in industrial buildings. Fig. 4 gives a comprehensive diagram of the prevalent temperatures at different points of the floor area as well as various elevations from the floor. The entire building was plotted into areas or stations, which would approximate the average temperatures of the whole, in an attempt to verify the assumptions and the results appear to justify the analysis. It will be noted that Station No. 4, in Fig. 4, which is the highest part of the building, consistently shows a lower temperature than at lower elevations. Station No. 3, in Fig. 4, in the center of the building shows the highest temperature, but this apparently is due to radiant heat from the hot air pipe. These thermometers were shielded from radiant heat effect (Station No. 3-S, Fig. 4), but it was decided that a true condition would be better shown by having uninsulated thermometers 1 ft. from the heat duct or at the uniform height of 14 ft. from the floor.

It will be noted in Fig. 4 that the average breathing line temperature was 52.7 deg. fahr., and the average temperature at the outside wall was 50 deg. fahr.

The general practice is to assume an inside temperature, usually at breathing line, from which the temperature difference is determined, and heat loss calculations made from the heat loss coefficient adopted by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. But it is evidenced in Fig. 4 that the average breathing-line temperature does not indicate the mean inside temperature in a system of this type. These analyses indicate advantages in the air heating principles, whether it be warm-air furnace or indirect steam. But a further observation brought out the fact that about three-fourths of the entire heating season there was little or no fire in the heater. It was estimated that about one-half of the time between October 1, 1924, and April 1, 1925, there was no fire in the heater at all; that most of this time there was oil-soaked wood and coal in the heater all set, ready for instant action in case the outside temperature would drop below 40 deg. This condition is made possible by the fact that a register temperature of 140 deg. could be obtained in 30 min., thereby removing any danger of

damage from freezing. Some fuel economy may be accounted for in this way and affect the computed efficiency.

The matter of maintenance expense for four years' heating service was investigated and found to be $30.80 for all repairs, including some fan-belt trouble and burned-out grate-bars. The fuel statement was checked through the owner who furnished delivery receipts, and a reliable check of the various coal companies in the city of Cleveland. This paper, presented as a non-technical field observation, sets forth various conditions, applications and results not found in the usual industrial heating practice, and gives a nucleus for further investigation.

DISCUSSION

E. K. CAMPBELL: A few years ago it was a common criticism of the Society that it was an organization of steam men, and that the warm air men had no chance and received no consideration. There seems to have been a decided change. Two papers on warm air heating on the program this morning are about the best indication of it.

There seem to me to be two things in this paper possibly open to criticism from the standpoint of the warm air furnace men themselves. The first is the method and the success of the distribution of temperature. The second is the method of computing the efficiency of the plant.

There are two theories of distribution within a large room which are struggling for supremacy, you might say, at the present time. One will probably win out in one class of building; the other in another class of building.

The system described in this paper is probably an extreme example of the system which depends upon velocity and the consequent injector action of the jet of air for distribution. I say an extreme example because the volume of air handled was so small in proportion to the size of the room. It figures out one volume of air moved about every 28 minutes. In the garage code which is coming up for discussion tomorrow morning, the Committee has placed, as a minimum for recirculation, a change every 20 minutes.

While the distribution in this particular case was sufficient for the purpose involved, it would hardly pass for any other class of building, and consequently a larger volume of air is necessary for what you might consider good distribution for the ordinary building outside of garages; particularly in audience rooms a much larger volume is necessary.

Hence the other theory of distribution is that of doing away with the distributing ducts within the room entirely and depending upon the large volume of air handled to get the distribution over the space involved, the theory being that the warm air coming into the room floats across the ceiling, not so much under the direct action of the fan as simply under the impetus given it by the elbow or particular form of the outlet.

Then as the cold air is drawn off the floor, the warm air is drawn down, evenly distributed over the space. In our own practice we have adopted a standard for audience rooms or rooms of similar character, of making a change every 10 minutes, 6 times an hour. That we find gives practically an even distribution over large rooms. We have applied that to rooms having several acres of floor space

and have recently applied it to the large room of the Butler University Field House in Indianapolis containing something like 4,500,000 cu. ft. of space in one room.

The settlement of the controversy, as we might call it, between the two theories will probably revolve around the dollars and cents. In garages and buildings of that type, where exact distribution is not necessary, the cheaper installation will finally take the field. In the other types of buildings, the large volume being necessary, and the distributing ducts within the room objectionable, the other theory will probably take the field.

Now, as to the method of computing the efficiency of the plant: I do not think any computation of efficiency which is based on an assumption for the 100 per cent is worth the paper it is written on; I do not care whether it is a steam plant, a furnace plant, or whatever it may be. So that I do not believe the computation of efficiency or the claim of 87 per cent efficiency in this paper amounts to very much, but the fact remains that this type of system, in quite general use in the central or middle west, has shown decided fuel economy as compared with the ordinary applications of steam heating. So that although the figures and the method of presentation are not convincing in themselves, I do not believe that he has greatly overstated the claim as to fuel economy of this type of system.

JOHN R. GASS: I think this paper on warm air heating in garages is very interesting, but to me the bigger problem in the garage is ventilation. No point has been made at all as to what is happening with the air that is being delivered into the building, and especially the exhaust from the cars.

I have in mind a design of a garage, a multiple-story building, and it is going to be necessary to dispose of the carbon monoxide gas from the cars. I wonder from this garage he has in mind, if any attempt has been made to dispose of that gas in this particular instance. Also what the effect would be for this type of system on a building having more than one floor.

It seems to me that there must be an outlet for the air that is blown in and in this case I think the air is no doubt exhausted through the roof ventilator, but if more floors are above the one floor, some other means has to be provided to get the air out.

Also in regard to the cost of heating this garage: he stated that only 18 tons of coal were used, but did not say how much crankcase oil was used. If that is converted into equivalent coal and any considerable amount of it used, I think his fuel bill was more than 18 tons.

The main point I wanted to bring out was the fact that proper ventilation is to me more important than proper heating because there are any number of ways in which the heat losses through the walls and roof could be compensated for by heating. Any of them would be satisfactory, but the proper distribution of the air, especially getting rid of the carbon monoxide and carbon dioxide gases that will form in the garage when any number of cars are running at one time, due to the fact that it is generally considered that those gases are heavier than air and fall to the floor, there is no provision in his plan to carry off those gases.

It always had been my impression that those gases were heavier than air and fell to the floor of their own accord, but I have been enlightened on the subject, and the fact is, carbon monoxide is lighter than air and will rise to the ceiling, if not

for the fact that the other gases form a blanket over the carbon monoxide and make them settle to the floor temporarily, and then is the time when the air should be drawn off the floor, before those other gases disintegrate and allow the carbon monoxide to separate from the other gases which then would rise to the ceiling, and it is a question in my mind as to whether or not the proper place to take the air is off the floor or off the ceiling.

It is interesting to note from his paper that the temperature at the ceiling was lower than at the floor. That is rather hard to believe unless you have actually tested it, because it is known and proved, of course, that the warm air will rise to the ceiling, and I just wonder if a great amount of air was not being lost or emitted through the monitor sky-light or if any means had been taken to determine how much air was being exhausted from the building.

F. A. KITCHEN: With reference to the heating and ventilation of garages, there are some interesting ideas brought out by this paper. The question of ventilation was just mentioned. It has been our observation that a large percentage of garages in the Middle West have no provision for positive ventilation of outside air and it will be a difficult thing to educate the garage operators to the higher requirement of the new ventilation code.

A forty-degree temperature is all that the garage operator wants, as his business is merely to keep cars from freezing. This low temperature requirement does make it entirely practical to fire only occasionally where such direct transmission heaters can attain a forty-degree temperature within a relatively short period.

This same method of heating has been used successfully in multi-storied ramp garages. A particular case in Kansas City illustrates the small fuel bill possible with similar equipment. A five-story garage for the past two years has averaged less than $250.00 for heating only.

I agree that some ventilation is necessary, but garage operators are not going to use the ventilation equipment which is extreme in its requirement.

Another point in connection with this paper is interesting. The usual method of estimating heat loss would be on the basis of a ten-foot room, adding a percentage for greater heights. I believe the distribution system plays an important part in the actual heat loss of a building and this paper shows with actual readings that with a distribution system properly designed and laid out, an entirely different result can be obtained with fan blast plants as compared to any gravity system.

One other question has been brought to our attention in garage heating and that is the temperature of material contained in the cars themselves. We are not at all sure that there is not an actual heat input to the building, say, in a five-story garage with four hundred cars passing in and out during the day.

We have calculated the average temperature of motor, body-cooling system in average car weighing 3000 lb. and from such meagre information as we could gather together, it is entirely possible that there would be a five- or even ten-degree higher temperature than the forty-degree room temperature. This might account for a considerable reduction in heat requirements.

E. B. LANGENBERG: There is one thing that I want to mention; that is, diffusion of the gases throughout the building; taking into consideration the infiltration

of air into that building with the number of cars that come and go, there is a constant diffusion of gases. We propose to conduct a test in St. Louis this fall to determine the amount of diffusion of those gases in a 4- and 7-story garage, and also under the three types of heating: steam, air blast and unit heater types, so I think by next January and possibly not later than the summer meeting next year, we can report something definite from the health viewpoint, as to the quality of gases as diffused by the different types of heating.

J. C. MILES: Before I start, I want to say this is not a ventilating system; this is a heating system.

In reference to Mr. Campbell's remarks about the computation of efficiency, the facts surrounding this computation are evidenced in the paper. Of course, we had to make some kind of a calculation to get a conclusion of some kind. When we were all done with it, it showed 87 per cent. You men are all familiar with this particular line of calculating heat losses and efficiency. I am offering this as my contribution, and you may arrive at another conclusion.

In reference to the number of air changes, the facts here brought out indicate that two air changes are enough for heating. This is a heating system.

In reference to the single outlet: I will say that I am inclined to think this is where we get our fuel economy. If this air floats across the ceiling, it would have a much higher ceiling temperature. If you will check up on the ceilings or roof losses of a factory or garage building, you will find it exceeds by two or three times the various amounts of heat loss in other parts of the building, so that floating hot air on the ceiling is where a lot of the fuel is wasted.

In answering Mr. Campbell, the distribution is down through the center of the building and that, to my mind, is paramount.

With reference to multiple-floor buildings, it is merely a matter of returning the air; of course, you have to pull the air out. All you need do is run a duct down from the upper floor of the building and pull the air down the same as from other portions of the building. The only difference from Mr. Campbell's idea is to have one opening on the first floor because no heat is lost on the ceiling. On the top floor it would be necessary to distribute the heat as we have it shown.

Mr. Kitchen's remark about the multiple-floors was answered by bringing the air down from the floor above, and distributing the heat from the ceiling on the top floor where the heat loss is greater.

In computing this efficiency I want you to notice on p. 379, Fig. 4, that under a typical observation, the temperature at the breathing line was 52 deg. fahr., so the temperature in this building was always above 40 and that efficiency of 87 per cent really does not apply. It does apply in our calculations, but does not apply to the actual conditions because the temperature was always above 40 deg. fahr. We had some heat from the engines, but this was over night storage of cars, and there wasn't a great deal. There was a little oil put into this furnace and some wood, for the purpose of starting the fires only, so we couldn't expect to get very much heat from that source.

The main thing that I am bringing out here, to answer Mr. Kitchen's last question, is that there is, in the final analysis, quite obviously a fuel economy.

No. 808

RELATIVE CONSUMPTION OF VARIOUS SOLID FUELS IN RESIDENCE HEATING[1]

By V. S. DAY,[2] URBANA, ILL.

MEMBER

Object

From the results obtained in the Research Residence of the *National Warm Air Heating Association*, at the University of Illinois, it is proposed to show comparisons of the relative economy of six distinct classes of solid fuels, and to show a method of approximating the consumption of any other solid fuel of known physical and chemical characteristics. The data were obtained in a warm air heating system, but inasmuch as the differences in economy of the six classes of fuel were due to combustion processes, rather than to the heat transmitting method and medium, the comparisons should be applicable to other systems of residence heating.

Description and Scope

A description of the Research Residence[3] is not essential to the subject matter of this paper. It is sufficient to note that 10 rooms in three stories were heated by a common type of warm air furnace, with a typical installation of pipes, 11 in number and totaling 832 sq. in. in cross-sectional area. The heat loss of the building for zero temperature and 15 miles per hour wind movement is 119,000 B.t.u. per hour. The furnace had 2.88 sq. ft. of grate area.

It is essential that the conditions under which the data were obtained be understood, and the following are the principal conditions. The Residence was heated day and night, with the exception of one small room which was occupied at night and was closed off. A temperature of 70 deg. fahr. average at the breathing level for the ten heated spaces was maintained with a dual system of thermostats. This control was adjusted to suit varying weather conditions, so that variations from the mean temperature at any one point in the Residence amounted to only 1 deg. fahr. Under this nice control the dampers opened to admit air to the fuel several times an hour, and combustion went on at a nearly uniform rate.

Fuel was fired four times in the 24-hour day. Each morning the ashes and sur-

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[1] Not to be reprinted except by permission of the Director of the Engineering Experiment Station, University of Illinois.

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[3] See Circular 15, Engineering Experiment Station, University of Illinois. "The Warm Air Heating Research Residence in Zero Weather."

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.

plus coal were removed, leaving a clean bed of coals at one-half firepot depth as shown by a definite marker. From the weight of fuel fired and the refuse withdrawn the daily fuel consumption was computed.

No lumps larger than 6 in. were fired, and all fines which resulted from breaking and handling were fired. The anthracite and coke were uniform in size, to pass a 3-in. screen. In firing the soft coal some pretense was made toward the so-called alternate method, and an effort made to prevent the formation of holes in the fuel bed.

All fuels were delivered to the Residence, and fired, without wetting. Samples were accumulated as the tests proceeded.

A chimney, 12 in. by 12 in. by 35 ft., and tile lined with 8-in. two-course brick surrounding, provided the draft. No check draft opening was used. A cross

TABLE 1. PROXIMATE ANALYSIS OF SIX FUELS

Fuel as Fired	Moisture, Per cent	Volatile, Per cent	Fixed carbon, Per cent	Ash, Per cent	Sulphur, Per cent	Value, B.t.u./lb.
Anthracite	4.24	5.79	78.22	11.75	0.59	12,618
By-pro. coke	1.00	0.77	88.66	9.57	0.69	13,100
Bitum. (Ill. poor)	8.86	36.07	42.18	12.89	4.10	11,178
Pocahontas	1.77	17.84	75.24	5.15	0.59	14,836
Bitum. (Ill. good)	8.40	32.00	50.89	8.71	0.72	11,881
Bitum. (E. Ken.)	1.76	37.10	53.96	7.18	1.13	13,698

damper was provided and used, with smoking at the fire door as a limiting condition.

Proximate analyses of the six fuels fired are given in Table 1, and it should be observed that they are of widely different characteristics.

Results of the tests are given in Table 2.

Analysis of Results

Inasmuch as weather conditions during each test, and consequently the rates of combustion, were not controllable, the procedure shown in Columns 4, 5 and 6 of Table 2 was followed to obtain an equal basis for comparing the results.

Column 4 shows the temperature difference between the air inside and outside of the house. The values shown in this column are proportional to the loads against which the heater was operating. These loads were unequal.

Column 5 shows the average combustion rate for the particular fuel, load, and for the particular number of tests.

Column 6, arrived at by dividing Column 5 values by Column 4 values, shows the coefficients upon which the relative consumptions of fuel were based.

This procedure is based on the assumption that the combustion rate is directly proportional to the indoor-outdoor temperature difference or temperature load. The assumption is not theoretically correct as the furnace efficiency is not constant for all rates of combustion, and the zero of combustion rate probably does not occur at zero temperature difference. However, the scatter of points on a graph of the relation was so great as to render impossible the accurate drawing of any line other than a straight line. Furthermore, the tests were all run at temperatures within

a few degrees of the seasonal normal. Under these conditions the assumption may be shown to be correct for practical purposes, and the values in Column 6 become the coefficients for computation of values in Columns 8, 9 and 12.

Column 7 is a conversion of Column 6 values from a weight basis to one of calorific value. It may be used to compare the fuels on the basis of thermal efficiency. The values show that fuels for which the smallest number of heat units were expended in heating the house were not the most economical fuels.

This over-all thermal efficiency is a very important consideration in residence heating, as with coke or anthracite coal it has been found that the over-all efficiency

TABLE 2. RESEARCH RESIDENCE ANALYSIS OF FUEL CONSUMPTION AND RELATIVE ECONOMY OF FUELS

1	2	3	4	5	6	7	8	9	10	11	12
Inc. Test No.		Number Tests Averaged	Av. Diff. Temp., In–Out	Av. Comb. Rate, Lb. per Sq. Ft. Grate per Hr.	Av. Comb. Rate per 1°, Diff. In–Out	Av. B.t.u. Expended per 1°, Diff. In–Out	Av. Comb. Rate, Zero Weather	Tons* Req'd for Equal Season	Ash to Handle, Lb.	Cost** per Ton at Urbana	Relative Cost of Heating, Dollars
194–103	Anthracite	9	41.5	1.90	0.0459	580	3.21	9.7	2280	16.50	160
118–120	Coke (By-product)	3	36.1	1.59	0.0440	576	3.08	9.4	1800	13.50	127
121–148	Bituminous (Inferior Ill.)	19	38.3	2.75	0.0720	806	5.04	15.4	3970	6.50	100
220–231	Pocahontas	11	33.8	1.40	0.0415	616	2.90	8.9	920	9.25	82
233–239	Bituminous (Good Ill.)	7	34.9	2.12	0.0608	722	4.25	13.0	2270	7.75	101
272–275 290–282	E. Kentucky	7	38.6	2.04	0.0529	725	3.70	11.3	1620	8.50	96

All tests made with dual thermostatic control.

* Season tonnage based on a load of 6160 deg.-days.

** Takes no account of variations in price during season, or account of locality.

is approximately 90 per cent, or in other words the final chimney loss is only 10 per cent of the heat of the fuel. With inferior fuels this over-all efficiency may be as low as 65 per cent, with 35 per cent of the heat of the fuel lost from the chimney.

Column 8 shows the probable combustion rate necessary to heat the house to 70 deg. fahr. in zero weather. This rate varies with different fuels of the same classification and the last two digits of the number cannot be regarded as definite.

Using Column 6 and a total seasonal heating load of 6160 degree-days the total seasonal tonnage shown in Column 9 was obtained. The values in Column 9 are in the same order as those of Column 6, and the transformation has been made simply to express the fuel consumption in the accepted mode. From the tonnage and the unit cost (Col. 11) the relative cost of operation shown in Column 12 was obtained.

A seasonal load of 6160 degree-days is nearly normal for the locality of the Research Residence and inasmuch as it was the actual seasonal load with the first

winter's fuel, anthracite, the consumption of each of the other fuels was calculated to the basis.

Column 11 shows the actual price paid for the fuels in the bin. These prices vary with season and location, and the values in Column 12 should be accepted with reservation. Different prices than quoted might easily affect a rearrangement of the values in Column 12.

The amount of ash handled with the six fuels is an important factor affecting their relative value as warm air furnace fuels. If the ash percentages of Table 1

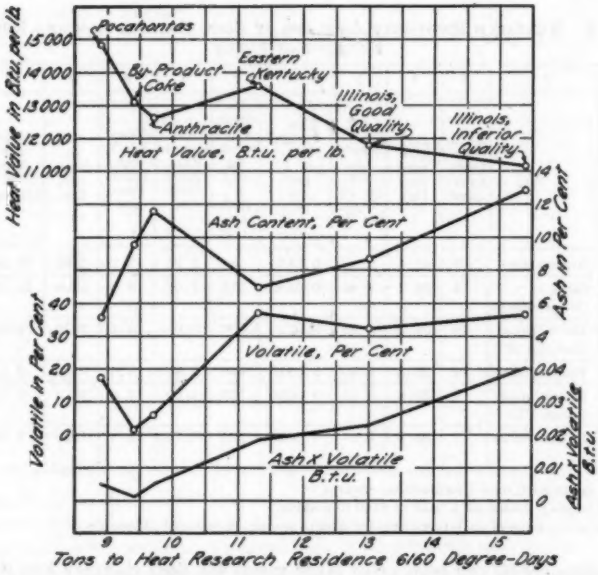

FIG. 1. CONSUMPTION OF VARIOUS TYPES OF FUEL IN TEST PLANT AND RELATION OF HEAT VALUE, VOLATILE AND ASH

are applied to the season tonnages of Table 2 it will be found that the weights of ashes carried away from the furnace, not accounting for coal which actually fell through the grates were as shown in Column 10.

Thus Table 2 shows that Pocahontas coal possessed the greatest number of economical characteristics, least tonnage, least ash handling and least cost. Soft coal, having the lowest unit price, was not the cheapest coal for the season and required the greatest tonnage. This fuel though unsatisfactory from the standpoint of smoke, soot, ashes and low thermal efficiency has one advantage, namely, quick ignition and acceleration of the fire, which makes it adaptable to intermittent firing.

Suggested Application

Critical examination of the values in Table 2 shows that no one chemical or physical characteristic of the fuels alone controls the consumption, hence the analysis shown in Fig. 1 has been attempted to reveal the effect of the predominant characteristics.

In Fig. 1 the heat value, ash percentage and volatile percentage, have all been plotted with seasonal tonnage as abscissae. The resulting graphs show certain tendencies, though erratic, as follows:

a. Tonnage varies inversely as heat value.
b. Tonnage varies directly as the ash.
c. Tonnage varies directly as the volatile.

These relations when combined indicate that tonnage varies directly as the product of ash times volatile and inversely as the heat value. A fourth graph has been drawn expressing this combined relation, and in this graph the erratic tendencies of the other three are minimized, so that it serves as an approximate measure of the tonnage required for any fuel of known characteristics. Thus for a fuel for which the fraction (ash times volatile divided by B.t.u. value) equals 0.02 the weight required would be 11.9 tons.

Similarly if a purchaser is offered two fuels at the same price he should choose that for which the fraction is least. Expressed in other words the graph means that for minimum consumption fuels having low values of the fraction are desirable. With this knowledge price may be combined with consumption in the intelligent selection of fuels for maximum value.

The graph may be further employed to approximate the consumption of any fuel in any residence by proportioning the tonnage and heat loss of the Research Residence (119,000 B.t.u. per hour at 0 deg. fahr. and 15 miles per hour wind) to the heat loss of the house in question (for the same conditions).

Attention is again directed to the test conditions and assumptions on which this analysis is based.

DISCUSSION

E. B. LANGENBERG (WRITTEN): The proverbial extravagance of the American public in the use of solid fuels is something that has been continenced and tolerated by the engineer and even reflecting in current designs of heating apparatus. Were it not for this extravagance, many heating systems would fail to function properly.

We all know the dangers of over-firing and the damage that is done to every plant by carelessness in this respect, but as far as the writer knows, no concentrated effort has been made to instruct the public in the proper use of solid fuels. It has only been within recent years that different firing instructions have been issued which were intended to cover the subject adequately.

There is no question but that the public will respond to a program of intelligent instruction that will provide them with the comfort they demand in home heating

Were engineers and manufacturers to take the table on page 387 and transpose it into simple layman language, the latter would be able to understand the relative values in the different types of fuels and purchase fuel in the most

economical way. Combining with this table, proper firing instructions, and determining for the owner the correct firing period together with an explanation of the results he may expect, will appeal to his imagination and he will respond to the suggestion.

There are, of course, other determining factors that control his purchase of fuel, but he at least will be advised of the correct type and quantity necessary to meet his requirements.

Publication of information of this character is highly desirable from the engineer's standpoint and this particular test stands out as it was made under actual working conditions in an actual residence and not under controlled conditions as would be the case in a laboratory experiment.

It would be well to continue these experiments and even though results might be erratic, they would at least show certain tendencies which the heating engineer must consider in his design of apparatus and installation.

The work of the Citizens' Smoke Abatement League in their campaign of smoke elimination in St. Louis has shown definitely that the consumer is extremely ignorant on fuel value and proper firing methods and because of this ignorance, the heating plant has failed to function in the most economical and efficient manner. During the past year, nearly 200,000 pieces of literature containing firing instructions have been issued by the League, and a report just issued by the League indicates a smoke reduction of 66 per cent in residence heating plants. In discussing this with other heating men the writer has been informed that complaints on heating apparatus failing to function has been reduced considerably. This would indicate that higher efficiencies are being developed by the consumer when proper firing methods are used.

PERCY NICHOLLS (WRITTEN): The type of tests being made by the University of Illinois is much needed. The facilities of the University's Research Residence permit of the accumulation of data which would give information on the following factors:

1. The relation between the efficiency of heating equipment as obtained on the test block and as obtained when installed and used under normal operating conditions.

2. The relative values when using different fuels.

3. The relation between the heat requirements computed for the whole buildings and the actual requirements.

Such information is needed to reconcile the results of laboratory tests of furnaces and of heat losses from buildings with the actual values as fixed by normal seasonal and operating conditions.

The paper by V. S. Day treats only the results as dependent on the fuels, but it is probable that the additional data collected would permit of the analyses being extended to give some information on items 1 and 3 above. The following conclusions have been deduced from the data given, although it is granted that investigations of the type under discussion must cover long periods before it is safe to generalize.

The paper suggests that the only heat of the coal not utilized when burning

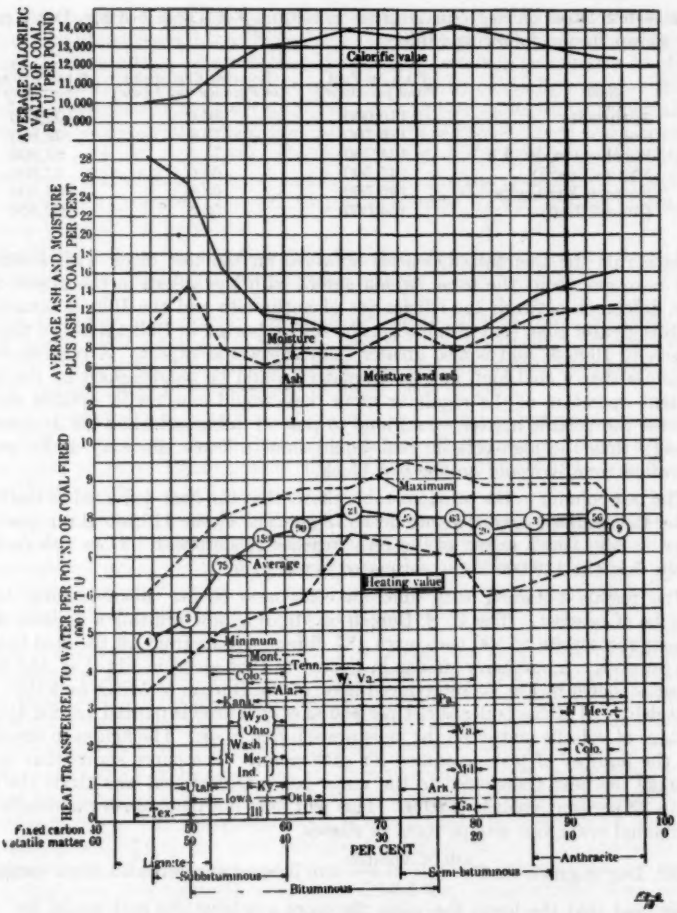

FIG. A. RELATIVE HEATING VALUES OF COALS WITH CORRESPONDING CALORIFIC VALUES AND PER CENT OF MOISTURE AND ASH

anthracite is 10 per cent lost in the flue gases. This is based on the assumption that the radiation loss from the furnace is usefully employed in the cellar. This estimate of heat loss is rather low for normal operation; 20 per cent for the average loss to the chimney and ash pit is more nearly correct, giving 80 per cent efficiency of furnace and grate for anthracite. Assuming this the relative efficiencies of the

fuels tested, based on the tonnage given in column 9 of Table 2 of Mr. Day's paper, are shown in the following table:

Fuel	B.t.u. in Fuel Fired per Hour	Relative Efficiencies of Furnace and Grate	B.t.u. Utilized per Hour
Anthracite	116,000	80.0	92,800
Coke	116,700	79.6	92,800
Pocahontas, W. Va.	124,700	74.5	92,800
Illinois (good)	145,500	64.0	92,800
Eastern Kentucky	146,500	63.4	92,800
Illinois (bad)	164,000	56.8	92,800

As a rule the thermal efficiencies obtained on the test block with anthracite and coke are about the same, which agrees with the values in the above table. The difference between the efficiencies of anthracite and the Illinois bituminous coals is greater than that obtained in the tests reported in Bulletin 141 of the University of Illinois, and is also greater than one would expect. A possible explanation is that a coal high in volatile matter would be handicapped by the intermittent operation of the regulator more than would one low in volatile matter, because the volatile matter would tend to pass off unburned when the damper was closed; thus the high-volatile coal would show a lower efficiency under service operation than it would on the test block.

The last column in the previous table shows that the heat delivered to the house under the assumed conditions would be 78 per cent of the 119,000 B.t.u. per hour given in Mr. Day's paper as the zero weather requirement. Does this fact not imply that the 119,000 B.t.u. estimated is too high?

The results obtained with different coals used to fire steam-heating boilers may be of interest. The U. S. Bureau of Mines is now printing a bulletin which reports the results of 500 tests with 187 different coals from all the coal fields of the country. A summary similar in import to that given in Fig. 1 of Mr. Day's paper is shown in Fig. A, reproduced here, of the Bureau of Mines bulletin. The heat delivered at the boiler outlet per pound of coal fired is plotted against the percentage of volatile matter on the moisture ash-free basis. The figures in the circles are the number of tests averaged for each point. The curve shows that on the average the heat transferred to the water per pound of coal was about the same up to 32 per cent volatile matter. This plot does not distinguish the results with individual coals, but groups them in classes.

Mr. Day suggests that $\frac{\text{ash} \times \text{volatile}}{\text{B.t.u.}}$ can be used as a criterion when comparing coals, and that the lower the value the more available the coal would be. It is not likely that this would be found to hold if more coals were tested and if they were more nearly alike. The expression is not logical except for the heating value varying directly as the B.t.u. per pound; however, it could be used as a guide if the coals differ widely in characteristics.

E. K. CAMPBELL: I think the information given in this paper is highly valuable, and of a definite character to the furnace men particularly. In fact, the experimentation at the University of Illinois has given a great mass of information which is only partly and very slowly being digested. And that is the thought that I

want to bring out in connection with this paper; that there is another conclusion that can be drawn from it that I think is of even greater importance than the comparison of fuel values, which is that the furnace tested is primarily a hard coal furnace; and that for the efficient burning of soft coal, especially the lower grades, a different type of furnace must be developed. Of course, the furnace men are up against the commercial proposition that they hardly ever know that a furnace when once sold will burn either hard or soft coal, continuously, so they depend largely on a sort of mongrel type, but I believe it is quite possible that a soft coal furnace can be developed that will be just as efficient for soft coal as the type of furnace tested is for hard coal.

Therefore, I draw the conclusion that this paper is just as much a test of the efficiency of the furnace for the different fuels as it is a fuel test.

E. S. HALLETT: The chart (p. 387) is of very great financial value, especially to us in St. Louis. For instance, I call your attention to that right hand column in which the cost of operating this building for a year, $160 for the anthracite, and so on down, the low grade bituminous coal is listed there at $100.

Now, in St. Louis that $100 would be $45 and all the others would remain the same. You see, then, where it puts us. We haven't any choice. I can't say that I am going to select Pocahontas or coke or anything of that kind; that thing is all cut out for me.

We have had this information essentially as given, and have acted upon the facts and are buying our coal in accordance with the facts shown here, but it would be impossible for me as an engineer to recommend any of the others except inferior Illinois coal because it shows the cost about half or something less than half of the cost of any other kind of coal to use in our particular place.

MR. LANGENBERG: Mr. Chairman, in reading this paper and preparing the discussion for it, my thought went a little further than just the analysis that has been made in this research work. In other words, I have tried to interpret it in terms of the consumer, that is, its application, and being more of a manufacturer than an engineer, I am interested in the application of this thing.

My one thought in bringing this to your attention is that instruction on how to use your apparatus is sadly lacking in the field. The public knows very little about how to use the apparatus. Two of the largest architects in St. Louis tell me, "They will put in the most complicated apparatus, and not tell us how to manipulate it. We hire some one to operate it for us and then do not get results. Why don't you give instructions in printed form that we can force these janitors and people who operate this apparatus to operate it in a particular way?"

It is very interesting to notice the results of the smoke abatement work we have done in St. Louis during the last twelve months, as it reflects this efficiency mentioned in the report just made.

They have made 46,331 calls. Householders instructed, 20,764; janitors instructed, 7629; complaints investigated, 538; smokers corrected, 3945. Those are definite corrections that have been made under observation of three or four weeks, and not the householder that has just received instructions. Here is what was found:

The manner in which we found hundreds of heating plants being operated in St. Louis is almost unbelievable. We have found boilers with doors, sections and smoke pipe held in place with baling wire. Sometimes the leaks in the sections were so bad that water leaking out of the boiler almost puts out the fire. We have found many boilers being fired with part or all of the grates missing. Down draft boilers are operated in every conceivable manner. Sometimes green coal is fired on the middle grates, more often the middle grates are used as an ashpit. We found one large down draft boiler with $3^1/_2$-in. tubes and the opening in the tubes was only about 1 in., the balance of the space being filled with soot. In this same boiler the ashpit and middle grates were filled with ashes and clinkers to within 2 in. of the upper grates. This boiler was being fired twenty-five times a day. Although this boiler was large enough to take care of a future addition to the building, they could not get sufficient heat to keep the building warm with an outside temperature of 15 degrees. After our men had thoroughly instructed the fireman and the boiler was thoroughly cleaned and operated properly, it was fired only four to six times in 24 hours and the owners reported a saving of 40 per cent in fuel.

Others have reported to us savings as high as 50 per cent. There is little doubt that under the conditions we found hundreds of heating plants being operated, the waste of fuel must have been at least 50 per cent. We found one fireman who for several years had been watching the chimney on the adjoining building to observe smoke conditions in his plant, notwithstanding the fact that this chimney was on the opposite side of the building from where the boiler was located.

They have determined in St. Louis very accurately—I think more accurately than for any other smoke campaign put on—the smoke densities from various types of buildings. The average reduction made in St. Louis and the suburbs was practically 46 per cent, and in residence work alone 66 per cent; and the results I am hearing from the heating men in the city is that the complaints for inefficient heating are becoming gradually eliminated.

These are things that the consumer must know. I think it is time the Society planned some kind of committee to draft rules for proper combustion and firing.

There are men who have been firing boilers for twenty-five years at about 45 per cent efficiency and who think they are doing a good job. Let's tell the users and the public how to handle our apparatus in an efficient way; then we will be on a little higher plane ourselves.

F. D. MENSING: If I were on the floor of Congress I would rise to tell you what a wonderful state Pennsylvania is. I am getting a little tired of hearing it said that anthracite coal is so high in price, and when it is referred to, the highest priced anthracite is quoted. I have been buying anthracite for my own use, and I have never paid more then ten dollars and a half a ton for it, even in war times. I now pay $7.50. Is it fair to run a test in the center of this country and add a high freight rate on anthracite? Would it not be better to deduct all freight rates?

There are two distinct types of anthracite. If we would learn to use those types, we would get better results. There is one, a white ash; another, a red ash. White ash will go to a powder, and it is hard to get a draft with it. Red ash coal is the finest fuel God put on this earth, bar none, for steam heating purposes. You can-

not stop it from clinking so you can't use it satisfactorily in the home. If you will mix those coals half and half you will get no clinker, and you will get no powder, and you will get a good draft, and you need not pay $16.50 a ton for coal; even in these times you should not pay more than $10.50 in Illinois, and if anybody is paying $16.50, come to me, and I will tell you how to save some money, and the price in the paper will drop on the scale from 160 to 100. The anthracite region in Pennsylvania needs business, and they are after it.

J. C. MILES: There is just one point I would like to bring out in connection with Professor Day's paper, and that is this: that Professor Day's experiment was with the kind of warm air furnace that is now being built and that the public will have to deal with, and it is my opinion that this is about the nearest conclusion that we can come to.

There are 265 furnace manufacturers in the country and there are about a thousand different kinds of furnaces. If you would line them all up and set them on a table and take the name off, it would be awfully hard to isolate one from the other except for difference in type. This analysis here, from a standpoint of efficiency and heating costs, is based upon the conditions in which the whole country has to operate, and I think that that is the analysis that we should be governed by.

V. S. DAY: In reply to Mr. Campbell's remarks about the furnace being primarily a hard coal burner; I agree with him that the furnace was of a type which would be sold now as a hard coal furnace. However, I think we have some important data in reply to him; that is this: in the case of every furnace which we have tested, although we have tested some sold as soft coal types, they showed higher efficiency with hard coal, even though they were manufactured and sold as soft coal burning furnaces.

There is not much I can say in reply to Mr. Hallett's remarks. His problem is in schools.

As far as residence heating is concerned, we feel that when the benefits of clean atmosphere are known that the problem will be solved by gasification or electrification or something like that, because, as Mr. Hallett says, he cannot compete with the smoke problem efficiently.

The same thing applies to Mr. Langenberg. He has accomplished some good results, but he has a long way to go. He neglected to say that the Bureau of Mines has pointed out that the smoke nuisance is the residence heater, not the large unit. You can instruct and penalize your fireman in apartment houses and factories and large institutions and make him minimize smoke, but the householder you cannot.

Mr. Nicholls' written discussion requires some consideration, and I will be as brief as possible on it. In the first place, I want to correct the impression that he may have received that there was an error in the work. The B.t.u. in the fuel burned he has given in the first page of his discussion as 116,000 and in this paper it is given as 119,500. He arrived at 116,000 by multiplying the coal values as given on the chart by 70. The paper stated a temperature of 70 degrees below zero and 15 miles wind velocity, and did not take into account wind velocity; therefore, there is an apparent discrepancy. There is no real discrepancy.

XUM

The heating efficiency of this house with anthracite figures 90 per cent, 10 per cent of the fuel being wasted from the top of the chimney without doing a particle of good except it is the cost of the draft. We must utilize it to create the draft to burn the fuel so it is difficult to say it is even a loss. So that which is not thermally useful is about 10 per cent with anthracite, and 35 per cent with lower grades of coal. Some of the other information, which you state as desirable to have, has been obtained. Circular 15 of the Engineering Experiment Station of the University of Illinois gives some information in brief, and two new publications are now in the process of printing. They will be available about September first, and much of the information requested is nearly available.

In reply to Mr. Mensing's statement about anthracite: anthracite coal in our locality has not been lower than $16.50 per ton since the war. All I can say about anthracite coal is that you haven't surveyed the market if you can sell it for $7.50 a ton. If you can compete, as you say you can, there is a real market for anthracite in Illinois, or in the West.

No. 809

COEFFICIENTS OF HEAT TRANSFER AS MEASURED UNDER NATURAL WEATHER CONDITIONS

By F. C. HOUGHTEN[1] AND C. G. F. ZOBEL[2]

PITTSBURGH, PA.

MEMBERS

DURING the past winter, the Research Laboratory of the A.S.H.&V.E. has made a study of heat loss through various types of building construction with the Nicholls heat meter. The types of walls studied were those outlined by the Technical Advisory Committee on Heat Transmission.

This report gives heat-transfer coefficients found for a number of types of construction and other characteristics of heat flow through walls under varying conditions. In making the investigation, it was hoped that certain conclusions could be drawn regarding:

1. Various coefficients entering into heat-loss computations for the different types of construction.
2. The accuracy of heat transmission coefficients now in use for certain types of walls which were derived from calculations based upon meager facts and questionable assumptions.
3. The applications of generally accepted coefficients to walls in buildings subjected to natural changing temperatures, and other climatic conditions.
4. The characteristics of heat flow in its relation to changing weather conditions, maximum and minimum temperature differences and other factors.
5. The practicability of the heat meter method of determining conductivity, conductance and inside and outside surface conductance coefficients.

Application of the Heat Meter

The method of applying the meter to walls, the observations necessary and methods of calculating results are discussed in other Laboratory reports,[3] and will be only briefly touched on in this paper.

Fig. 1 shows the heat meter, *A*, and the other instruments necessary for its use; these consist of standard physical laboratory equipment of the highest sensitivity.

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[2] Research Physicist.

[3] Measuring Heat Transmission in Building Structures and a Heat Transmission Meter, by P. Nicholls, published in JOURNAL of A.S.H.&V.E., January, 1924.

Report on Heat Flow through a Roof by Research Laboratory, by Carl Zobel, published in JOURNAL of A.S.H.&V.E., May, 1927.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.

The meter itself is a thin plate 24 in. square by about 1/8 in. thick. It can be applied to any wall for measuring heat flow, provided that the surface is plain and smooth enough to offer intimate contact between the meter and the wall. Usually the meter has been applied to the inner finished surface. It may, however, be applied to rougher surfaces by using an intermediate pad of soft material which will adjust itself to the irregularities of the wall and eliminate air circulation between the meter and the wall surface.

In order to use the meter in a large number of domestic and commercial buildings without interfering with wall decorations, and in many cases with normal occu-

FIG. 1. HEAT METER AND APPARATUS IN SCHENLEY APARTMENTS

pancy of the space, as well as to expedite changing the set-up from one building to another, it was desirable to make certain changes in the earlier laboratory application and technique.

Fig. 2 shows a convenient method of applying the meter to a wall. The simple stand takes up little space, and does not materially interfere with normal air circulation over the section of wall studied. By applying sufficient weight to the base of the stand, the necessary pressure for holding the plate tightly against the wall can be applied by the adjustable screw. All wires leading from the meter to the auxiliary instruments are contained in a cable, making it possible to place the instrument table at some distance, also to study several types of wall construction in different parts of the building. Cables from each meter are brought to the instrument table where observations can be made on any wall at will by means of a selective switch. With this application the meter has been used in office, home and factory without materially interfering with normal occupancy.

Fig. 1 shows two of the meters applied to a wall in the Schenley Apartments in Pittsburgh.

Results of Investigation on Heat Flow

Table 1 is a list of the different walls studied and heat-transfer coefficients obtained. The list includes a number of types of construction other than those mentioned in the list suggested by the Technical Advisory Committee. These data were collected simultaneously with other types of construction suggested by the Committee.

Figs. 3 to 13, inclusive, show some of the constructions tested.

Fig. 14 is a log of heat flow and accompanying temperatures for several days for the Schenley Apartment, and Fig. 15 is a like log for Webster Hall.

The coefficients considered in this report and their significance are as follows:

C = Conductance = B.t.u./sq. ft./hr./degree temp. difference between surfaces

h_i = Inside surface conductance = B.t.u./sq. ft./hr./degree temp. difference between inside surface and air.

h_o = Outside surface conductance = B.t.u./sq. ft./hr./degree temp. difference between outside surface and air.

U = Transmittance = B.t.u./sq.ft./hr./degree temp. difference between inside and outside air.

From Fig. 14, the log for the brick veneer tile wall in the Schenley Apartments, it is found that at 11 A.M., January 16, the heat flow through the top section of the north wall was 15.5 B.t.u. per sq. ft. per hr., also that the temperature difference between the inside and outside wall surfaces was 47 deg. fahr., therefore, C, conductance is $\frac{15.5}{47}$ or 0.33. The instantaneous values for h_i, h_o, and U are obtained in the same manner using the proper temperature differences.

Table 2 gives the bi-hourly values for this wall section for the entire day of January 16. These bi-hourly values for each day are averaged over the entire 24 hr. and are called the daily averages, which are given in Table 3. These daily averages are in turn averaged, and the final averages corrected for heat capacity if necessary in order to obtain the accepted factors given in Table 1.

If this method of analyzing the data is accurate to within the limits of the Nicholls heat meter which is 5 per cent the resulting figure for conductance should check to within 5 per cent the value for conductance obtained by taking an average over a period such that the average temperature of the wall at the start and finish of the period is the same. For example: taking the same wall section, it is found that the average conductance for January 14 to 17, inclusive, is 0.298. This is obtained from the daily averages after correcting them for heat capacity. If approximately the same period is considered, namely, from 12 P.M. of January 14 to 12 P.M. of January 17, at the beginning and end of which period the average temperature of the wall was the same and an average taken of the bi-hourly values for conductance uncorrected for heat capacity, the result is 0.288 or a difference in the two methods of 0.01. The actual per cent change or difference is $\frac{0.01}{0.298} \times 100$ or 3.4 per cent, which is within the accuracy claimed for the meter.

Discussion of Results

The variation in coefficients in Tables 2 and 3 is due to several variables including rate of change in mean temperature and actual mean temperature of the wall tested.

When the temperature of the wall is changing, all of the heat that passes through

TABLE 1. HEAT TRANSMISSION DATA

PROJECT.	DATE.	NO. OF DAYS.	CONSTRUCTION.
BUREAU OF MINES	AUGUST, 1926.	15	2¼" T&G PINE, FELT, 3/16" SLATE.
			PLASTER ON WIRE NETTING.
BENNETT LUMBER & MFG. CO.	DECEMBER, 1926.	15	BARRETT 5 PLY ROOFING, 1¾" PINE.
			8" DOUBLE SHELL GLAZED TILE. VERT. AIR SPACE.
			SAME AS ABOVE, BUT FOR SECOND FLOOR.
SCHENLEY APTS.	JANUARY, 1827.	15	4" BRICK, 8" TILE. PLASTER, PAINT.
			" " " "
			PLASTER, 3" PYROBAR, PLASTER.
GAMMON'S LUNCHROOM.	FEBRUARY, 1927.	11	4" BRICK, 8" BACKER-HEADER TILE, PLASTER.
			" " "
WEBSTER HALL.	FEBRUARY, 1927.	10	4" BRICK, 5" TILE, PLASTER.
			" " "
LABORATORY.	MARCH, 1927.	7	13" BRICK. PLASTER.
HOTEL SCHENLEY.	MARCH, 1927.	8	4" BRICK, 8" TILE. PLASTER.
OLIVER BLDG. ROOM 812.	MARCH, 1927.	8	(1½" TERRA COTTA, 13" BRICK, ½" CEMENT,
ROOM 1607.	MARCH, 1927.	7	3" FURRING TILE, PLASTER.)
WESTINGHOUSE, INSULATED.	APRIL, 1927.	8	4" BRICK, 5" TILE, ½" CEMENT, 1½" CORKBOARD, PLASTER
			2" CORKBOARD, PLASTER.
WESTINGHOUSE, UNINSULATED.	APRIL, 1927.	8	4" BRICK, 5" TILE, PLASTER.
			LATH, PLASTER.
LABORATORY.	JUNE, 1927.	8	6" CONCRETE SLAB #1, 1:2:4 MIX.
MINE SAFETY APPLIANCES CO.	AUGUST, 1927.	21	TAR ROOFING, 1" CONCRETE, 4" CINDERS, 1½" CONCRETE,
			SLAG COVERED ROOFING, 1¾" T & G.
W.A. BODE CO.	SEPTEMBER, 1927.	21	CONCRETE TILE, 30" PAPER, 1" SHEATHING.
LABORATORY.	NOVEMBER, 1927.	3	8" CONCRETE SLAB #1, 1:2:4 MIX.
	NOVEMBER, 1927.	4	8" CONCRETE SLAB #2, 1:2:5 MIX.
	DECEMBER, 1927.	5	8" CONCRETE SLAB #2, 1:2:5 MIX.
	JANUARY, 1928.	4	8" CONCRETE SLAB #2, 1:2:5 MIX.
	FEBRUARY, 1928.	18	(CLAPBOARD, PAPER, SHEATHING, STUDDING,
			LATH & PLASTER, WALL PAPER.)

C—Conductance—B.t.u. per sq. ft. per hour per deg. fahr. difference between surface temperatures.

h_i—Inside surface conductance—B.t.u. per sq. ft. per hour per deg. fahr. difference between inside air and surface temperatures.

h_o—Outside surface conductance—B.t.u. per sq. ft. per hour per deg. fahr. difference between outside air and surface temperatures.

the meter does not pass completely through the wall. When the temperature of the wall is rising while heat is flowing outward, some of the heat measured by the meter is required to raise the temperature of the wall. Hence, some only enters the surface, while the remainder passes into the wall to greater depths. Only a portion of the total quantity of heat entering the meter leaves the cold side. It is obvious therefore that the outside surface coefficients should show considerable

variation with changing temperature, whereas the conductivity or conductance coefficient calculated from the heat measured must also be in error to a lesser degree.

It is well known that most materials show an increased conductivity with a higher mean temperature of the material, hence heat transmission coefficients

DEVELOPED WITH NICHOLLS HEAT METER

EXPOSURE.	No. OF TESTS	C	h_i	h_o	U	$U_{comp.}$	t_m	IN CONDITIONS	OUT CONDITIONS
SOUTH ROOF.	1	.36	1.25	—	—	—	94°	ATTIC SLOPING ROOF	21% SUN
EAST "	1	—	—	—	—	—	—		
NORTH "	1	—	—	—	—	—	—		
CEILING.	1	1.64	1.47	2.07	.57	.57	75°		
FLAT ROOF.	1	.46	1.25	2.08	.29	.29	58°	NEW PLANED SURFACE	17% SUN, WIND 11 M.P.H., CLOUDY.
SOUTH WALL	1	.40	.89	1.55	.24	.23	39°		
	1	.40	—	—	—	—	37°		
NORTH WALL	2	.30	1.30	1.44	.21	.21	30°	METER NEAR RADIATOR & WINDOW	21% SUN, WIND 12.4 M.P.H. CLOUDY.
EAST WALL	2	.34	.80	1.63	.21	.21	46°		
PARTITION.	1	.67	1.50	2.60	.45	.45	63°	WINDOW OPENED OFTEN ON EAST SIDE	WINDOW OPENED SPASMODICALLY.
WEST WALL.	1	.31	1.17	3.83	.23	.23	55°	NATURAL	31% SUN, WIND 11 M.P.H. CLOUDY.
" "	1	†.42	1.30	3.83	.30	.29	—	EAST EXPOSED TO STEAM & DRAFTS	
NORTH WALL	2	.46	1.56	1.75	.24	.23	48°		23% SUN, WIND 13.4 M.P.H., CLOUDY.
EAST WALL.	2	.46	1.60	1.60	.30	.30	52°		
	2	.28	.52	3.76	.17	.17	94°	EXPOSED TO RADIATION	10 M.P.H. WIND.
EAST WALL.	2	†.50	1.17	4.13	.36	.36	52°	NEAR WINDOW & PARTITION	15% SUN, WIND 13 M.P.H., CLOUDY.
NORTH WALL	2	.20	1.41	1.73	.15	.16	49°		66% SUN, WIND 11 M.P.H., PT. CLDY.
NORTH WALL	2	.19	1.05	2.15	.15	.15	56°	CONVECTION OBSTRUCTED	51% SUN, WIND 13 M.P.H., CLOUDY.
R.	1	.15	.69	.92	.11	.11	35°		71% SUN, WIND 13.4 M.P.H., PT. CLDY.
CEILING	1	.19	.98	1.46	.15	.15	61°		
	1	.45	2.10	3.20	.32	.33	56°	AFFECTED BY RADIATION	71% SUN, WIND 13.4 M.P.H., PT. CLDY.
	1	2.46	.93	1.35	.69	.69	78°		
	4	1.79	—	—	—	—	78°		
FLAT ROOF	DAY	.05*	.81	.41	.04	—	85°	WHITE CONCRETE SURFACE	47% SUN, WIND 8 M.P.H., PT. CLDY.
	SHADE	.43	1.63	3.66	.35	—	51°		
FLAT ROOF	DAY	.13	1.63	.70	.12	—	91°	PAINTED WOOD SURFACE	47% SUN, WIND 8 M.P.H. PT. CLDY.
	NIGHT	.34	1.45	2.41	.31	—	58°		
HIP ROOF	DAY	.02	.84	.41	.02	—	76°	NEWLY PLANED WOOD SURFACE	65% SUN, WIND 9 M.P.H. PT. CLDY.
	NIGHT	.32	1.49	.96	.30	—	76°		
	4	1.64	—	—	—	—	73°	AGED 4 MONTHS	
	4	2.05	—	—	—	—	60°		
	4	1.97	—	—	—	—	60°	AGED 27 DAYS	
	4	1.90	—	—	—	—	77°	AGED 71 DAYS	
WALL	1	.30	.51	1.70	.17	.17	111°	EXPOSED TO RADIATION	STILL AIR.
	1	.28	.61	2.40	.18	.18	94°	EXPOSED TO RADIATION	WIND 2.4 M.P.H.

U—Transmittance—B.t.u. per sq. ft. per hour per deg. fahr. difference between inside and outside air temperatures.

$U_{comp.}$—Same as *U* but computed from *C*, h_i, h_o in Table 1.

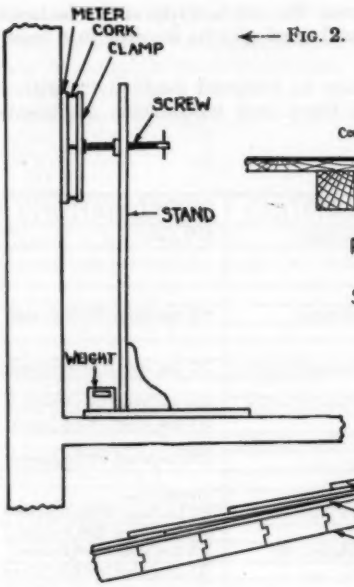
t_m—Average temperature—deg. fahr.

*—Value taken from A.S.H.&V.E. GUIDE or computed.

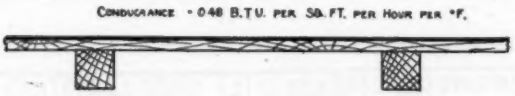
†—Special cases.

determined under varying temperature conditions must show a variation due to this cause.

In order to observe any relation between rate of change in the mean temperature of the wall and conductance, all bi-hourly determinations on the north wall of the Schenley Apartments for January 11 to 19, 1927 are plotted in Fig. 16 against the rate of change in mean wall temperature.



← FIG. 2. SKETCH OF HEAT METER CLAMP AND STAND



ROOF 1" × 5½" T & G. YELLOW PINE,
5-PLY BARRETT ROOFING,
SUPPORT 6"×6", 4 FEET ON CENTER

FIG. 4. BARRETT ROOF

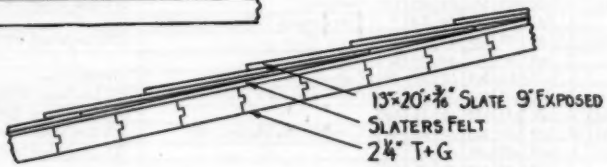


FIG. 3. SLATE ROOF

C=0.40
C IN B.T.U. PER SQ. FT. PER HOUR
PER °F BETWEEN SURFACES.

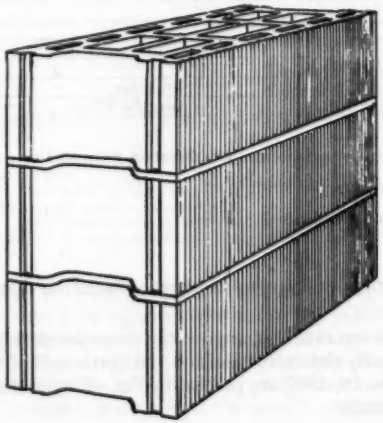


FIG. 5. DOUBLE SHELL GLAZED TILE WALL

8" DOUBLE SHELL GLAZED TILE, COMBED FACE.

The rate of change in mean temperature was determined by dividing the total change in temperature between two consecutive bi-hourly readings by the time elapsing and applying this rate of change to the time half-way between the two. When the temperature of the wall was rising, the rate of change was indicated as positive and while falling as negative. Although the individual points show great variation there is an unmistakable tendency to form a well-defined curve. The variations of the individual readings from this curve as drawn is much less pronounced than the variation in the magnitude of the individual determinations of the conductance coefficient.

In order to see whether the individual readings throughout a test showed any relation to the mean temperature of the wall, the bi-hourly conductance coefficients corrected for storage of heat in the wall due to change in temperature are plotted against mean temperature of the wall in Fig. 17. Again there is consider-

TABLE 2. BI-HOURLY VALUES FOR C, h_i, h_o, U. FOR WALL OF SCHENLEY APARTMENTS

Time	C	h_i	h_o	U
1 A.M.	0.26	1.64	1.01	0.18
3 A.M.	0.28	1.32	1.23	0.20
5 A.M.	0.29	1.38	1.28	0.20
7 A.M.	0.30	1.39	1.30	0.21
9 A.M.	0.31	1.22	1.39	0.21
11 A.M.	0.33	1.35	..	0.25
1 P.M.	0.34	1.47	1.48	0.23
3 P.M.	0.35	1.17	1.33	0.22
5 P.M.	0.35	1.32	1.61	0.25
7 P.M.	0.32	1.09	1.30	0.21
9 P.M.	..	1.10	1.11	0.18
12 P.M.	0.30	..	1.23	0.22
Average	0.31	1.31	1.30	0.21

able variation in the individual values. There is, however, an apparent tendency toward a curve sloping downward to the left. The curve as drawn indicates an increase in the conductance coefficient of $^1/_{100}$ B.t.u./per sq. ft./per hour/per degree temperature difference for a mean temperature rise of 7.0 deg. fahr.

Because of this change in the transfer coefficients with temperature it is usual to express such coefficients for some definite temperature of the wall. The Code of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS for testing insulated walls specifies that such tests should be made with a mean wall temperature of 40 deg. fahr.

In determining heat loss from buildings under winter conditions the temperature of the wall cannot be controlled, and the results given in this paper are for the particular mean wall temperatures which happen to pertain at the time.

In determining heat transfer coefficients with the heat meter where the rate of flow and mean temperature of the wall depend upon natural weather conditions, results must be corrected for change in temperature of the wall unless data are collected over a period long enough to eliminate the effect of this error. As a rule it is possible in a test extending over three or four days to pick such a period that the mean temperature of the wall at the beginning and end are the same.

SCHENLEY APTS.

DATE	EXPOSURE	C1	ΔC	C	EXPOSURE	C1	ΔC	C
	North	-	-	-	East	0.35	-0.04	0.34
		0.34	-0.03	0.31		.39	-.03	.36
		.37	+.05	.42		.41	-.02	.39
		.32	+.05	.37		.40	-.03	.37
		.31	+.05	.36		.41	-.04	.37
		.31	+.05	.36		.40	-.04	.36
		.30	-.01	.29		.40	-.03	.37
		.31	-.02	.29		.38	-.02	.36
		.31	-.03	.28		.38	-.01	.37
		.30	-.02

Results Tabulated

The results presented in Tables 1 to 3 show the least variation in the conductance coefficients, a greater variation in the inside surface coefficients, and the greatest variation in the outside surface coefficients. These differences are inherent in the method of test. With any method of test it is more difficult to determine surface coefficients to the same degree of accuracy as it is to determine a conductivity or conductance coefficient.

With the meter method of test, natural conditions of weather and air motion pertain. Even near the inside surface there is present the natural convection currents which take place in normally occupied space; hence the variation in the inside surface coefficient h_i.

There is considerably greater variation in air currents and wind velocity as well as variation in sunshine and other radiation effects on the outside surface of a wall. One should expect a great variation in these coefficients determined under

TABLE 3. DAILY VALUES FOR C, h_i, h_o, U. FOR WALL OF SCHENLEY APARTMENTS

Date	C	h_i	h_o	U
1–12–27	0.336	1.38	1.22	0.22
1–13–27	0.365	1.45	1.70	0.25
1–14–27	0.215	1.43	0.59	0.15
1–15–27	0.244	1.47	1.08	0.18
1–16–27	0.305	1.31	1.30	0.21
1–17–27	0.378	1.40	1.96	0.26
1–18–27	0.351	1.35	1.65	0.23
1–19–27	0.251	1.06	1.24	0.20
Average	0.306	1.36	1.34	0.21

natural conditions. In calculating heat loss it is customary to apply different outside surface coefficients depending upon the wind velocity. Although it is possible to obtain rather definite outside surface coefficients under laboratory conditions when a definite air velocity over the surface is maintained, it is doubtful to what extent such coefficients apply under natural conditions. For instance, with a 15-mile wind, one may find from actual test a much smaller velocity than this near the surface of a wall depending upon the direction of impingement and other surrounding conditions. The very variation in the individual values for outside surface transmission as given in this report is of considerable value in indicating to what extent these values may be evaluated for different wind conditions.

Data on Wind Collected

Throughout the investigation at the Laboratory, observations on wind as given by the Weather Bureau and also as determined at various points near the wall tested have been recorded, with the hope that the various factors involved could be evaluated. So far, little or no direct correlation has been found. However, a more complete analysis will be made of the data already in hand, together with additional data to be collected with a view of solving this problem. It is hoped that it may be possible to differentiate between the different variables and arrive

at a practical method of determining outside surface coefficients with the meter under actual conditions.

It has been shown that there is greater variation in the coefficients found for the two surfaces, particularly for the outer surface, than is found for conductance or conductivity. This is not as serious as one might assume without further consideration. The relative importance of the conductance or conductivity coefficient and the inside and outside surface coefficients depends upon the total resistance which the wall offers to heat flow. The better insulated the wall the smaller the relative importance of the surface coefficients. In order to bring this fact out more clearly, Table 4 has been prepared. Three of the walls tested having total transmission coefficients ranging from 0.11 to 0.30 are considered. For each wall there is given the total transmission U as accepted in Table 1, as well as the accepted values for conductance and inside and outside surface coefficients. There are given in addition three other values of U, respectively, based upon a 10 per cent

TABLE 4. VARIATION IN U AS AFFECTED BY DEVIATION IN C, h_i, h_o

Place	Accepted Values from Table 1				Values of U Based upon 10% Decrease in			Per Cent Decrease in U Due to 10% Decrease in		
	C	h_i	h_o	U	C	h_i	h_o	C	h_i	h_o
Westinghouse Insulated	0.15	0.89	0.92	0.1126	0.1040	0.1111	0.1112	7.64	1.33	1.24
Schenley Apartments	0.30	1.30	1.44	0.2087	0.1935	0.2049	0.2051	7.28	1.82	1.72
Webster Hall	0.48	1.60	1.60	0.3000	0.2805	0.2937	0.2937	6.50	2.10	2.10

decrease in the magnitude of the accepted conductance, inside surface and outside surface coefficients.

It will be observed that for the wall with U equal 0.11, the 10 per cent change in h_i, h_o and C effect changes of 7.6, 1.3 and 1.2 per cent in U while for the wall, U = 0.30, the same per cent variations in the three coefficients give variations of 6.5, 2.1, 2.1, respectively, in U.

Computing Heat Transfer

In estimating heat loss, the engineer bases his calculations on experience and accepted heat transmission coefficients. The question immediately arises as to what wall areas to use, particularly for small wall sections around windows. It is obvious that greater heat loss occurs through such sections of walls than for larger sections. Some of the walls tested shed light on this question.

Referring to the factors for the wall of Hotel Schenley, conductance is given in Table 1 as 0.60. This value is too high, probably because of the position of the meter on a narrow strip of wall between a window and partition.

Fig. 18 shows a section of the wall and the probable fanning out of the lines of heat flow to the larger outside surface extending from the center of the partition to the window sash. This no doubt accounts for the conductance of 0.60 which is about double the value found for a similar wall of larger area in the Schenley Apartments.

It is of interest to note the change in the maximum rate of heat loss and total heat loss for a 12-hour period, during a cold wave. During the study of the tile, brick veneer wall, a drop in the outside temperature occurred, followed by a gradual temperature rise. The depression in temperature continued over a 3-day period from January 13 to 16. The outside temperature, maximum rates of heat flow, total heat flow and per cent deviation are given in Table 5.

It will be seen that the maximum measured rate of heat flow increased as the

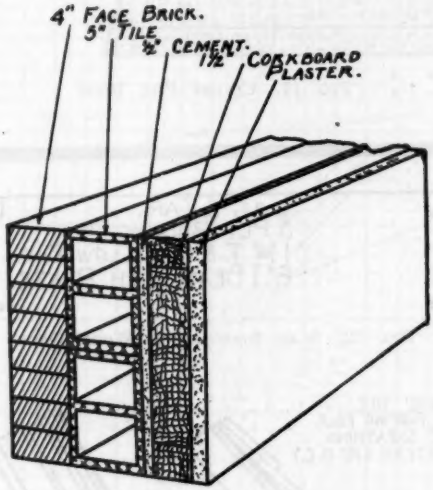


FIG. 10. INSULATED TILE, BRICK VENEER WALL

outside temperature fell, but not as rapidly as the theoretical rate of flow found by multiplying the conductance of the wall by the temperature difference. As the outside temperature started to rise the measured rate of flow became greater than the theoretical rate.

The difference is due to the lag in heat loss due to the heat capacity of the wall. The total heat loss over the 12-hour period as measured is less than the computed loss, based upon a continued maximum temperature difference over the entire period. This is a fact which is not always taken into account in estimating heat loss from buildings.

Computed Values and Test Figures Check

Referring to Table 1 it is noted that coefficients are given for two walls differing in construction only by a layer of $1^1/_2$-in. corkboard insulation. The walls of these Westinghouse houses are of brick, hollow tile and plaster. A comparison

FIG. 11. CINDER FILL ROOF

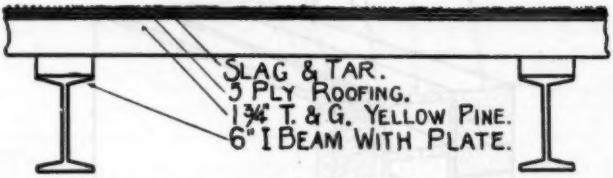


FIG. 12. SLAG ROOFING ON WOOD DECK

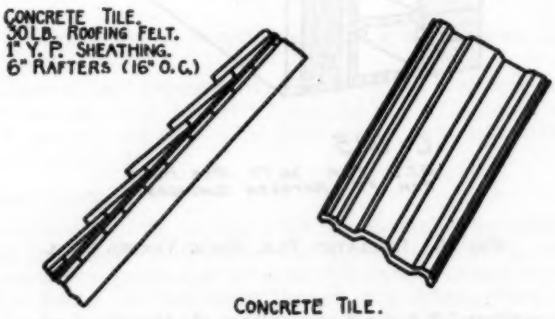


FIG. 13. CORRUGATED CONCRETE TILE ROOF

of the conductance for the insulated wall, as computed from the conductance of the uninsulated wall and the conductivity of corkboard, with the conductance derived from actual measurements affords a check on the application of the accepted formula for calculating overall coefficients from conductivities of the component parts of the wall.

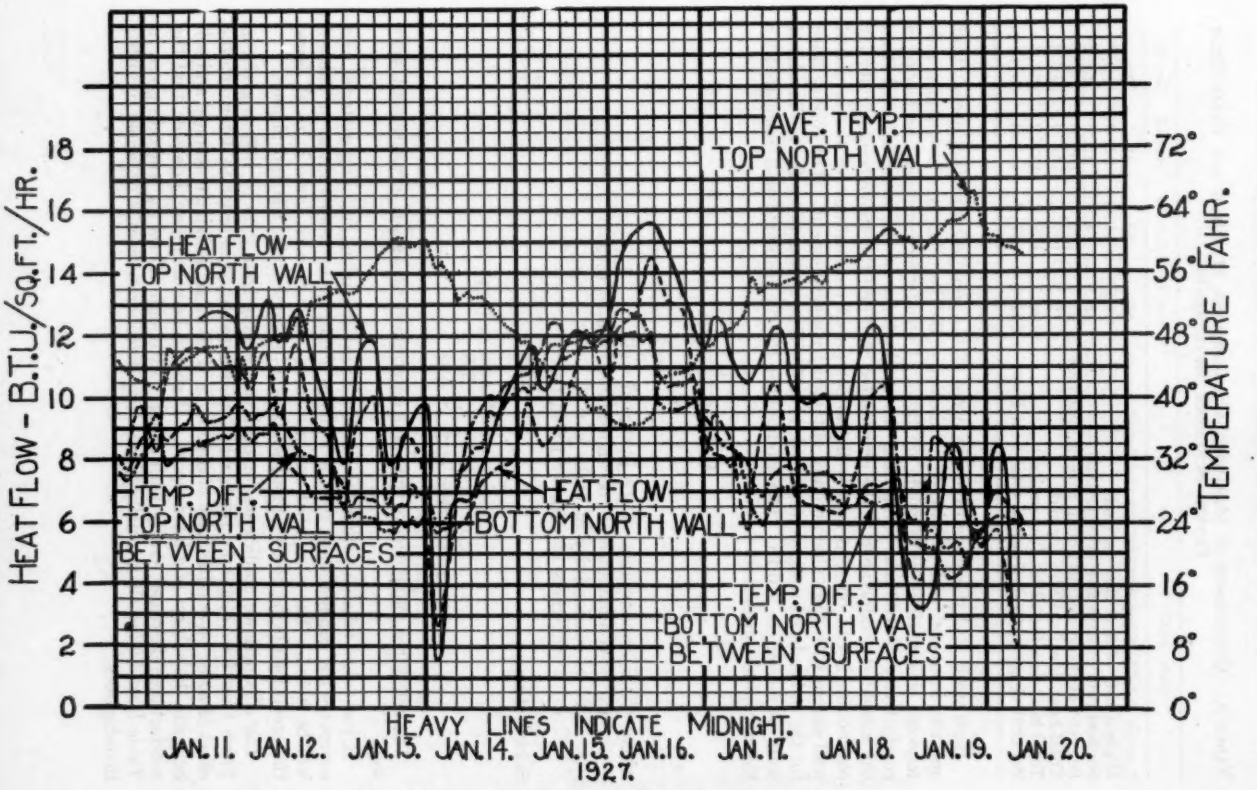

HEAT FLOW - B.T.U./SQ.FT./HR.
TEMPERATURE FAHR.
AVE. TEMP. TOP NORTH WALL
HEAT FLOW TOP NORTH WALL
TEMP. DIFF. TOP NORTH WALL BETWEEN SURFACES
HEAT FLOW BOTTOM NORTH WALL
TEMP. DIFF. BOTTOM NORTH WALL BETWEEN SURFACES
HEAVY LINES INDICATE MIDNIGHT.
JAN. 11. JAN. 12. JAN. 13. JAN. 14. JAN. 15. JAN. 16. JAN. 17. JAN. 18. JAN. 19. JAN. 20.
1927.

FIG. 14. LOG OF HEAT FLOW FOR SCHENLEY APARTMENTS

TABLE 5. COMPARISON OF MEASURED AND COMPUTED MAXIMUM AND TOTAL HEAT FLOWS—SCHENLEY APARTMENTS

Date, 1927	Jan. 13	Jan. 14	Jan. 15	Jan. 16
Lowest outside temperature	40	23	18	20
Highest rate of heat flow (actual)	9.5	11.4	15.3	15.7
Highest rate of heat flow (theoretical)	8.9	14.0	15.6	15.1
Per cent of theoretical of actual rate of heat flow	93.7	122.1	102.0	96.1
Total heat flow for 12 hr. (actual)	72.2	122.4	168.3	143.3
Total heat flow for 12 hr. (theoretical)	106.7	168.0	187.2	153.6
Per cent of theoretical of actual total heat flow	147.8	137.2	111.2	107.1

Both walls had the same exposure, were of the same construction except that one was insulated with 1½ in. of corkboard while the other was not, and simultaneous observations were made on both. Considering corkboard as having a conductivity of 0.30 and computing the conductance of the insulated wall from the measured conductance of the uninsulated wall and the above conductivity for corkboard, it can be seen how well the computed conductance of the insulated wall agrees with the value actually obtained by measurement. The conductance for the uninsulated wall, as measured, is 0.45. The conductance for the insulated wall, as measured, is 0.15. The conductance for the insulated wall calculated by the accepted formula is

$$C = \frac{1}{\frac{1}{C_1} + \frac{d}{K}}$$

where C = conductance of the insulated wall
C_1 = conductance of the uninsulated wall = 0.45
K = conductivity of cork = 0.30
d = thickness of cork = 1.5 inches.

Substituting:

$$C = \frac{1}{\frac{1}{0.45} + \frac{1.5}{0.30}} = 0.14$$

The computed value checks the value determined by actual measurement very well.

If one takes reliable values for conductivities of various building material and computes the conductances for the walls in Table 1, the results given in Table 6 will be noted. The computed and measured conductances agree in most cases, the exceptions being concrete and walls of 4-in. brick, 5-in. tile and plaster.

The conductance coefficients for concrete ranging from 2.05 to 1.66 as given in Table 1 are for a slab 8 in. thick, which is being studied in order to determine the effect of aging on conductivity of concrete. This study is being continued and will be made the subject of a later report. It should be noted here, however, that the conductance decreases slowly with aging. Although values for concrete given in Table 1 are higher than usually given, they corroborate results obtained by other investigators.

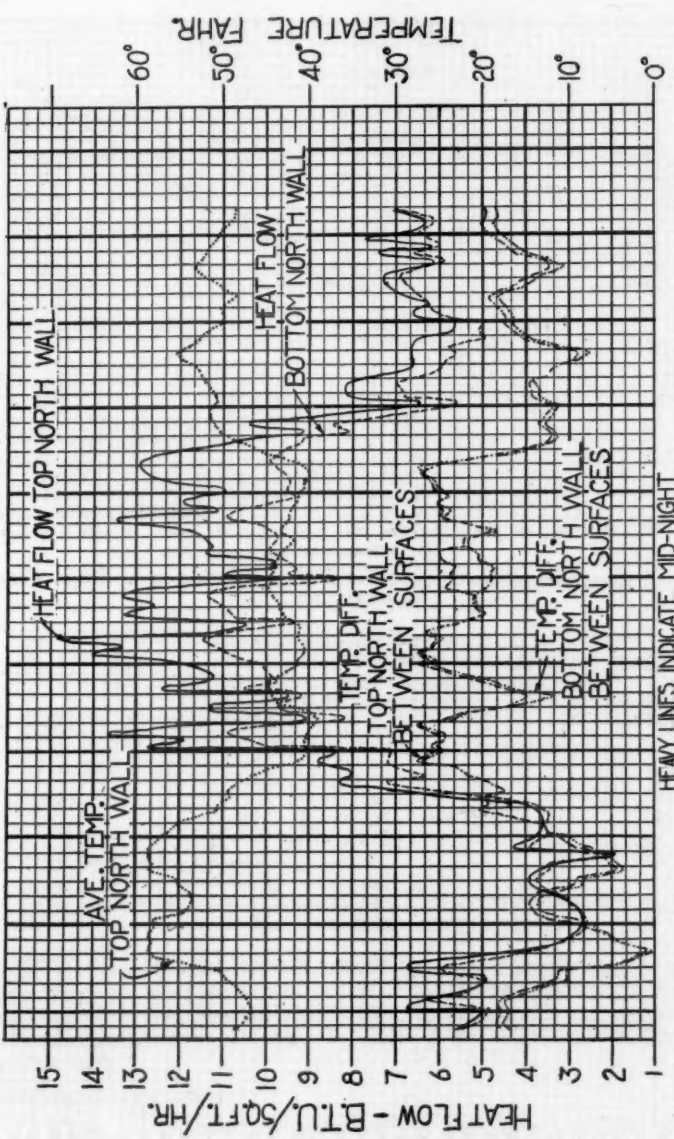

HEAT FLOW - B.T.U./SQ.FT./HR.
TEMPERATURE FAHR.
HEAT FLOW TOP NORTH WALL
AVE. TEMP. TOP NORTH WALL
HEAT FLOW BOTTOM NORTH WALL
TEMP. DIFF. TOP NORTH WALL BETWEEN SURFACES
TEMP. DIFF. BOTTOM NORTH WALL BETWEEN SURFACES
HEAVY LINES INDICATE MID-NIGHT
FEB. 16 FEB. 17 FEB. 18 FEB. 19 FEB. 20 FEB. 21 FEB. 22 FEB. 23 FEB. 24 FEB. 25
1927

FIG. 15. LOG OF HEAT FLOW FOR WEBSTER HALL HOTEL

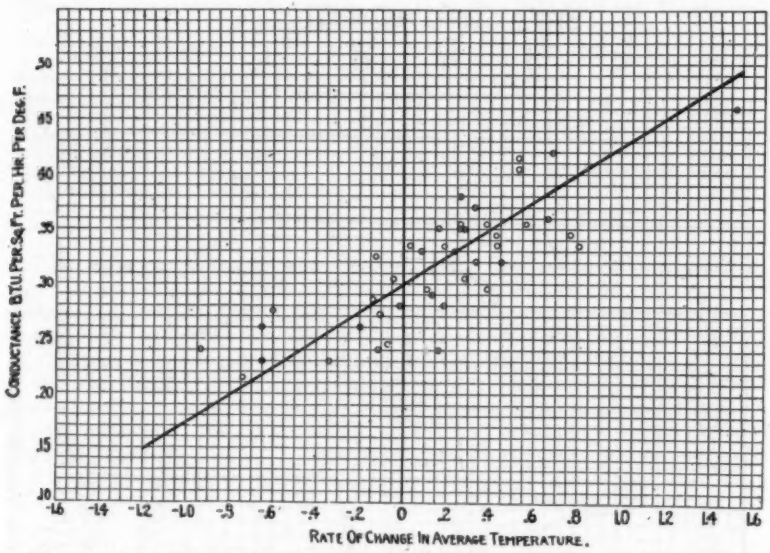


FIG. 16. VARIATION IN CONDUCTANCE WITH RATE OF CHANGE IN MEAN WALL TEMPERATURE

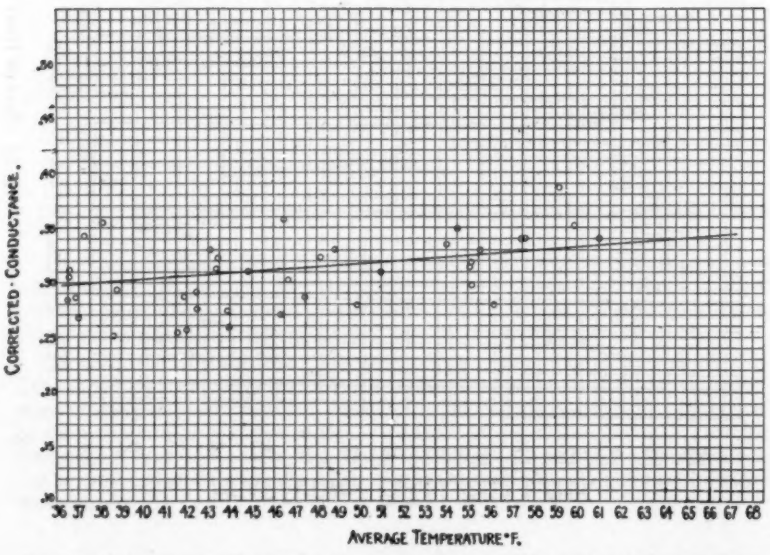


FIG. 17. VARIATION IN CORRECTED CONDUCTANCE WITH MEAN WALL TEMPERATURE

TABLE 6. COMPARISON OF MEASURED AND COMPUTED CONDUCTANCES

Project	Construction	C Measured	C Computed
Bureau of Mines Experiment Station	$2^1/_4$-in. T. G. felt, $^3/_{16}$-in. slate	0.36	0.37
	Plaster on wire netting, $1^3/_8$ in.	1.64	1.68
Bennett Lumber Co.	Barrett 5-ply roofing, $1^3/_4$-in. pine	0.46	0.48
	8-in. double shell glazed tile	0.40	0.43
Schenley Apartments partition	4-in. brick, 8-in. tile, plaster, paint	0.30	0.31
	Plaster, 3-in. pyrobar, plaster	0.87	0.88
Gammons lunch room	4-in. brick, 8-in. backer-header tile, plaster	0.31	0.31
Webster Hall	4-in. brick, 5-in. tile, plaster	0.48	0.38
Laboratory	13-in. brick, plaster	0.28	0.30
Hotel Schenley	4-in. brick, 8-in. tile, plaster	0.60	0.31
Oliver Building 812 1607	$1^1/_2$-in. terra-cotta, 19-in. brick, $^1/_2$-inch cement, 3-in. furring tile, plaster	0.19	0.19
Westinghouse insulated ceiling	4-in. brick, 5-in. tile, $1^1/_2$-in. cork, plaster	0.15	0.13
	2-in. corkboard, plaster	0.19	0.15
Westinghouse uninsulated ceiling	4-in. brick, 5-in. tile, plaster	0.45	0.38
	Lath, plaster	2.48	2.00
Laboratory	8-in. concrete slab, 1:2:4 mix	1.79	1.04
Mine Safety Appliances Co.	Tar roofing 1-in. concrete, 4-in. cinders, $1^1/_2$-in. concrete	0.10	0.16
	Slag-covered roofing, $1^3/_4$-in. T. G.	0.38	0.40
W. A. Bode Co.	Concrete tile, No. 30 paper, 1-in. sheathing	0.33	0.35
Laboratory	8-in. concrete slab No. 1, 1:2:4 mix	1.66	1.04
	8-in. concrete slab No. 2, 1:2:5 mix	2.05	0.78
	8-in. concrete slab No. 2, 1:2:5 mix, 27 days	1.97	
	8-in. concrete slab No. 2, 1:2:5 mix, 71 days	1.90	
	Clapboard, paper, sheathing, studding, lath, plaster, wall paper	0.28	0.27

The conductances were computed according to the formula

$$C = \frac{1}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \cdots \frac{d_n}{K_n}}$$

where C = conductance,
d = thickness in inches,
K = conductivity.

The conductivities for the various materials used in computing C are given in Table 7.

Table 1 contains values for 4-in. brick, 5-in. tile and plaster obtained from five determinations on as many wall sections found in three different walls in two buildings. All these determinations check, indicating that the coefficients assumed in calculating the value given in Table 6 do not apply to the materials found in these walls.

Summary and Conclusions

1. Table 1 is presented giving the various coefficients found and conditions

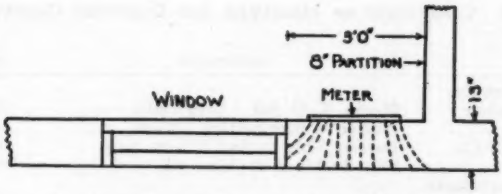


FIG. 18. WALL SECTION OF HOTEL SCHENLEY

for which they apply, for 44 sections of building construction of 19 different types. The values given were obtained from actual test on buildings in Pittsburgh and with a few exceptions check computed values for conductances.

2. The conductance found by measurement for three walls containing hollow tile are higher than such coefficients computed from accepted values for conductivity, indicating that such accepted values do not apply to the tile tested.

3. The coefficients found by measurement for concrete are higher than those usually accepted. This, however, is in agreement with work of others and may be accredited to the fact that the sample tested had not aged sufficiently.

4. Some aspects of heat loss are brought out for small wall sections between heavy partitions and windows, errors in computing heat loss by assuming maximum rates of heat flow due to maximum temperature differences as applying during the whole day, changing temperature and mean temperature of the wall, and for the comparison of conductance values derived by computation with those found by actual measurement.

TABLE 7. CONDUCTIVITIES OF BUILDING MATERIALS

Material	K
Yellow pine sheathing	1.00
Felt[a]	3.00
Slate	10.37
Plaster	8.00
8-in. double shell tile[a]	0.43
Brick (dry)	4.00
Brick (wet)	5.00
Pyrobar	1.00
5-in. tile	0.58
Terra-cotta	8.00
Cement	8.00
3-in. tile[a]	0.80
Corkboard	0.30
Concrete 1:2:4 mix	8.30
Concrete 1:2:5 mix	6.27
Cinders	0.70
Slag-covered roofing[a]	1.32
Concrete tile	8.00
Gypsum plaster	2.32
Wood lath and plaster[a]	2.00

[a] For construction used.
In most cases the above values were taken from the A.S.H.&V.E. GUIDE, 1928.

No. 810

HEAT TRANSFER THROUGH ROOFS UNDER SUMMER CONDITIONS

By F. C. HOUGHTEN[1] AND C. G. F. ZOBEL,[2] PITTSBURGH, PA.

MEMBERS

INCREASE in the practice of conditioning air in industrial and domestic buildings makes the resistance to, and characteristics of heat flow through the roof of increasing importance to the engineer. The flow of heat into buildings in summer is fully as important as heat loss in winter and the accompanying rise in temperature in summer is more difficult to counteract than temperature fall in winter.

This report gives heat transfer coefficients for three types of roof as determined by the Nicholls heat flow meter, characteristics of heat flow in summer, and the effect of radiation from the sun, radiation to the sky, condition of the roof surface and sprinkling with water.

Types of Roofs Studied and Method Used

One roof studied is of cinder-fill concrete construction in a four-story brick factory building of the Mine Safety Appliances Co. Fig. 1 shows the construction of the roof and space below. A complete record of the rate of heat flow and accompanying phenomena was made on three sections of the roof, over a period of 21 days from July 31 to August 19, 1927.

Another roof is of slag and tar on five-ply roofing paper, laid on $1^3/_4$-in. T and G sheathing. It is on a two-story brick factory building of the Mine Safety Appliances Co. Fig. 2 shows details of construction and general characteristics of the space below. The study was made on one section of the roof with a single meter, over a period of 21 days from July 31 to August 19, 1927.

Observations of heat transfer characteristics were taken on a concrete tile roof on a small one-story and attic real estate office of the W. A. Bode Co. Two meters recorded the heat flow through two sections of this roof and Fig. 3 shows the details of construction of this roof and the space below.

The Nicholls heat flow meter was used for determining the rate of heat flow and in each case the instrument was applied to the under side of the roof. Description, method of application and operation of this instrument are recorded in other

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[2] Research Physicist.

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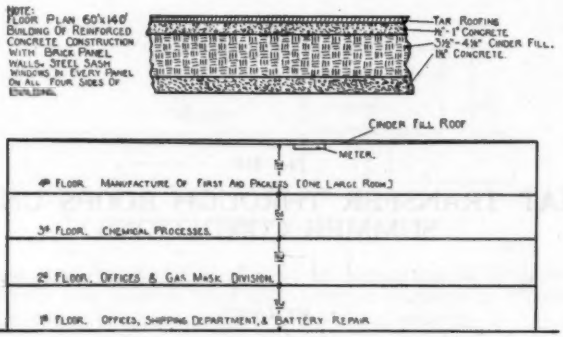
NOTE:
FLOOR PLAN 60'x140'
BUILDING OF REINFORCED CONCRETE CONSTRUCTION WITH BRICK PANEL WALLS. STEEL SASH WINDOWS IN EVERY PANEL ON ALL FOUR SIDES OF BUILDING.
TAR ROOFING
½"-1" CONCRETE
3½"-4½" CINDER FILL.
12" CONCRETE.
CINDER FILL ROOF
METER.
4th FLOOR. MANUFACTURE OF FIRST AID PACKETS (ONE LARGE ROOM.)
3d FLOOR. CHEMICAL PROCESSES.
2d FLOOR. OFFICES & GAS MASK DIVISION.
1st FLOOR. OFFICES, SHIPPING DEPARTMENT, & BATTERY REPAIR.

FIG. 1. MINE SAFETY APPLIANCES BUILDING—CINDER FILL ROOF

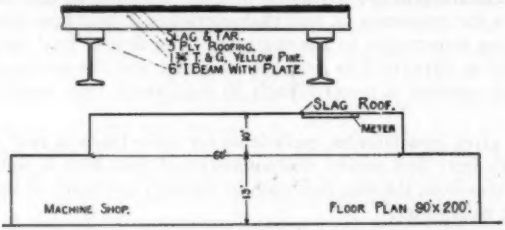

FIG. 2. MINE SAFETY APPLIANCES BUILDING—SLAG-SURFACED ROOF

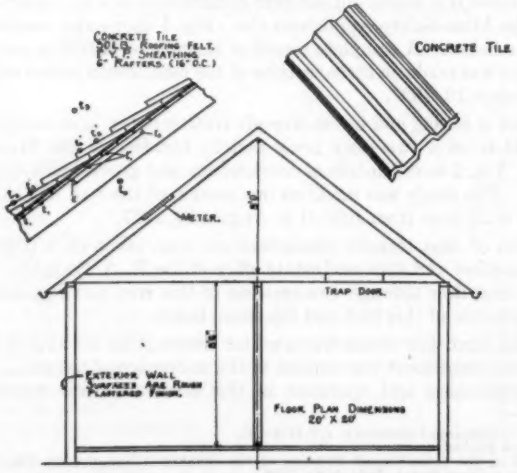

FIG. 3. CORRUGATED CONCRETE TILE ROOF ON BODE REAL ESTATE OFFICE

Laboratory reports[3] and will not be repeated here. The reliability of the meter as an instrument for indicating rate of heat flow, also its worth for determining conductance coefficients of walls has been amply demonstrated. Its application to the determination of inside and outside surface conductance coefficients and transmittance coefficients in the field, where temperature, wind and other natural phenomena are not controlled, have not, however, been satisfactorily demonstrated.

An attempt is made in the analysis of the data presented in this report to arrive at a better understanding of the application of the heat-meter method in determining these coefficients.

Heat Flow Data

Fig. 4 is a log of heat flow, temperatures and temperature differences found for a concrete tile roof over a period of 14 days from September 14 to September 27, 1927. The study of this roof was continued through October 4. Two meters were used on two different sections of the roof.

From September 14 to 18, inclusive, the section over one or both of the meters was sprinkled with water in order to determine its effect on heat flow. From September 23 to 29, inclusive, a determination was made of the effect of color and character of the surface on heat absorption, radiation and flow, by covering the sections of the roof over the two meters with black or white oilcloth. During the remainder of the investigation of this roof, data were collected under existing conditions.

Fig. 5 shows more clearly the relation of heat flow to outside and inside air temperature for the sprinkled and unsprinkled sections of the roof. Fig. 6 gives similar data for the effect of color and Fig. 7 gives data for a short period under conditions of normal flow.

Heat flow through a slag-surfaced roof on the plant of the Mine Safety Appliances Co. was measured for 21 days from July 31 until August 19, 1927. Fig. 8 is a log of flow and temperature difference for a portion of this period, August 2 to 7, inclusive, where only one meter was used. During the same period, three meters were used to obtain the heat flow through a cinder-fill roof on an adjoining part of the same building, and Fig. 9 gives a log of the findings over a period of 6 days. For comparison of results the heat-flow curve for the slag-surfaced roof during the same period is superimposed upon the curves for heat flows through the cinder-fill roof.

An inspection of the data presented in Figs. 4 to 9 impresses one with the fact that heat flow through a roof in summer is by no means a simple or continuous phenomena. Almost without exception there are two complete reversals of flow in each 24-hour period. The resultant flow in either direction, over a period of several days, is never large and may be in either direction—that is, to say, the heat flow into the building through the roof during the day is about equal to the heat flow out during the night. The maximum rate of heat flow inward during the day is much higher than the maximum rate of flow outward at night, but heat flows out over a greater part of the 24-hour period.

The short duration of flow inward is striking and varies somewhat with the heat

[3] P. Nicholls, Measuring Heat Transmission in Building Structure and a Heat Transmission Meter, TRANSACTIONS, A.S.H.&V.E., Vol. 30, 1924, pp. 65–104.
Carl Zobel, Report on Heat Flow through Roof by Research Laboratory, JOURNAL A.S.H.&V.E., Vol. 33, No. 5, May, 1927, pp. 309–325.

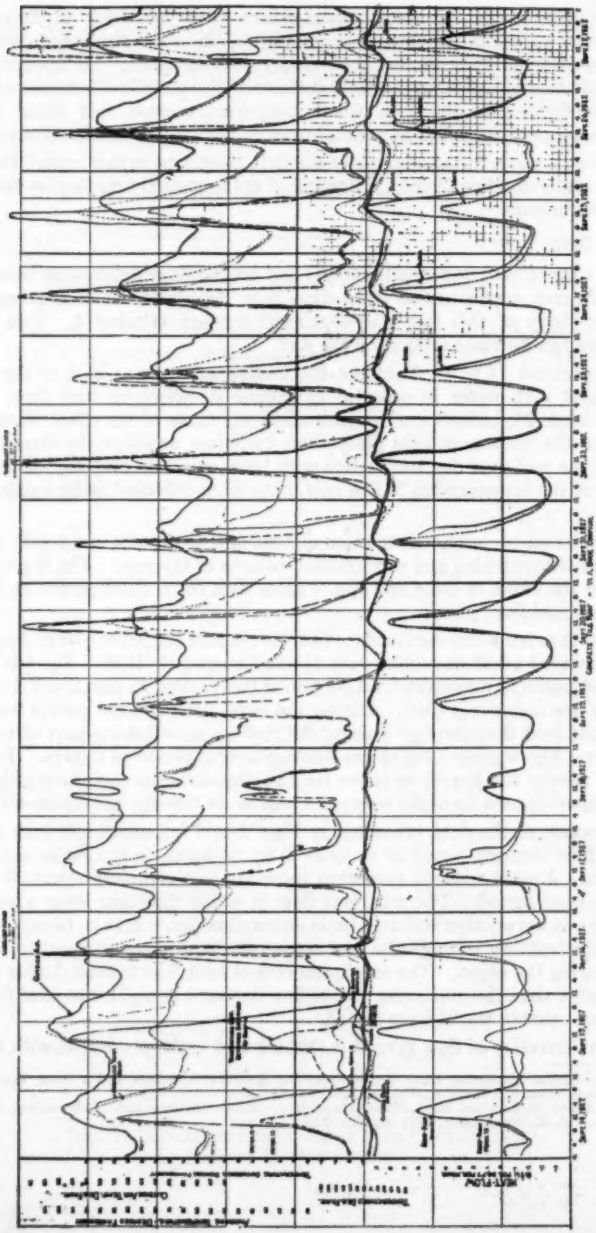

FIG. 4. LOG OF HEAT FLOW FOR CONCRETE TILE ROOF

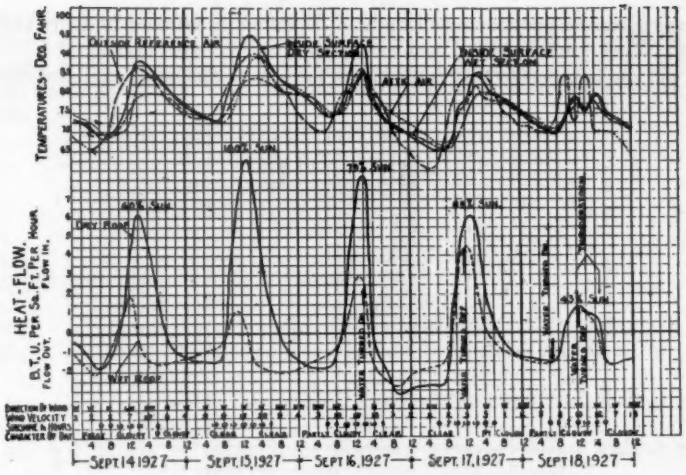

FIG. 5. LOG OF HEAT FLOW FOR CONCRETE TILE ROOF WHILE SPRINKLED

capacity and thermal resistance of the roof. For the concrete tile roof the average period of inward flow was 10 hours, while the maximum and minimum lengths of this period were 12 and 6 hours. For the slag-surfaced and cinder-fill roofs the

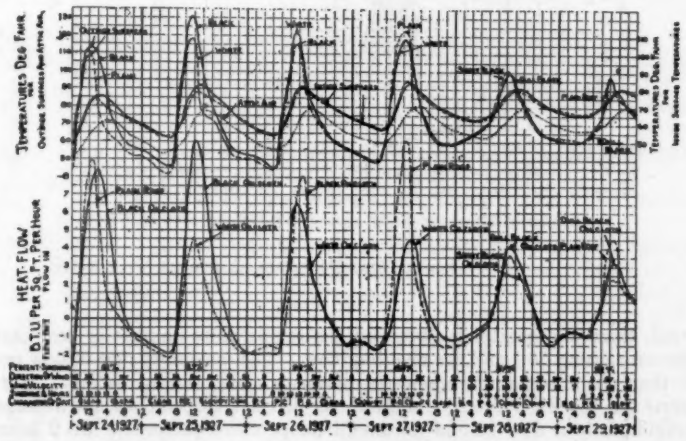

FIG. 6. LOG OF HEAT FLOW FOR CONCRETE TILE ROOF WHILE COVERED

average maximum and minimum lengths of the inflow period were 10 hours and 15 hours; 12 hours and 20 hours; and 5 hours and 7 hours, respectively.

It will also be observed that in the case of the heavier and better insulated cinder-

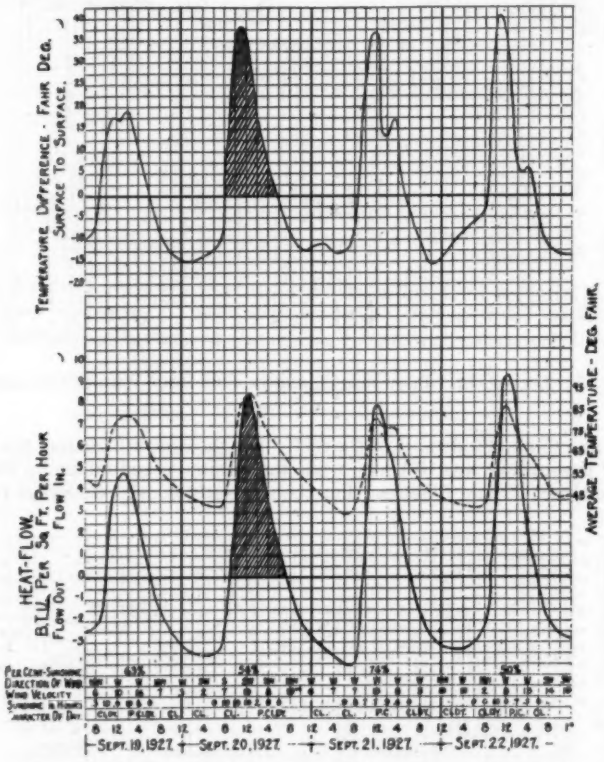

FIG. 7. LOG OF NATURAL HEAT FLOW FOR CONCRETE TILE ROOF

fill roof, there is a greater lag between the temperature impulse or temperature difference causing flow and the resulting flow. The maximum rate of flow occurs later than the maximum temperature difference which causes the flow. For the concrete tile, the slag-surfaced and the cinder-fill roofs, respectively, the average lag of maximum heat flow behind maximum temperature differences are 2 hours, 3 hours and 8 hours during the day, and 4 hours, 5 hours and 9 hours during the night.

Nomenclature and Computation of Coefficients

The nomenclature in this report conforms to the standard terms tentatively adopted by Sub-committee *C*, of the Committee on Heat Transmission of the National Research Council. Fig. 10 shows where the observations defined below were made.

t_o = Inside air temperature
t_1 = Inside surface temperature
t_2 = Outside surface temperature
t_3 = Outside air temperature
t_2 = Outside surface temperature over meter
t_7 = Inside surface temperature in contact with meter
E = Differential E. M. F. across meter
t_o = Temperature of meter
H_m = Average rate of heat flow through meter B.t.u./sq. ft./hr.
H_m = Average rate of heat flow unaffected by meter B.t.u./sq. ft./hr.
T_{H_m} = Time of heat flow, hours
$\Delta t_{1'} = t_1 - t_2$ = Temperature difference between surfaces over meter deg. fahr.
$\Delta t_{2'} = t_1 - t_2$ = Temperature difference between surfaces without meter, deg. fahr.
C = Apparent conductance B.t.u./sq. ft./hr./deg. fahr. difference between surfaces
h_i = Inside surface conductance, B.t.u./sq. ft./hr./deg. fahr. difference between inside surface and inside air
h_o = Apparent outside surface conductance B.t.u./sq. ft./hr./deg. fahr. difference between outside surface and outside air
U = Apparent transmittance, B.t.u./sq. ft./hr./deg. fahr. difference between outside surface and outside air
ΔC = Correction to apparent conductance for heat capacity
Δh_o = Correction to apparent outside surface conductance for heat capacity
ΔU = Correction to apparent transmittance for heat capacity
$C = C + \Delta C$ = conductance, B.t.u./sq. ft./hr./deg. fahr. between surfaces
$h_i = h_i$ = inside surface conductance, B.t.u./sq. ft./hr./deg. fahr. between inside surface and air
$h_o = h_o + \Delta h_o$ = outside surface conductance, B.t.u./sq. ft./hr./deg. fahr. between outside surface and air
$U = U + \Delta U$ = transmittance, B.t.u./sq. ft./hr./deg. fahr. between air temperatures
$\Delta t_{h_o} = t_2 - t_3$
$\Delta t_{h_i} = t_1 - t_1$
$\Delta t_U = t_o - t_3$
$\Delta t_m = \frac{t_1 + t_2}{2}$ = Average temperature of construction
T_c = Time-interval for temperature difference for conductance, hours
T_{h_o} = Time-interval for temperature difference for inside surface conductance, hours

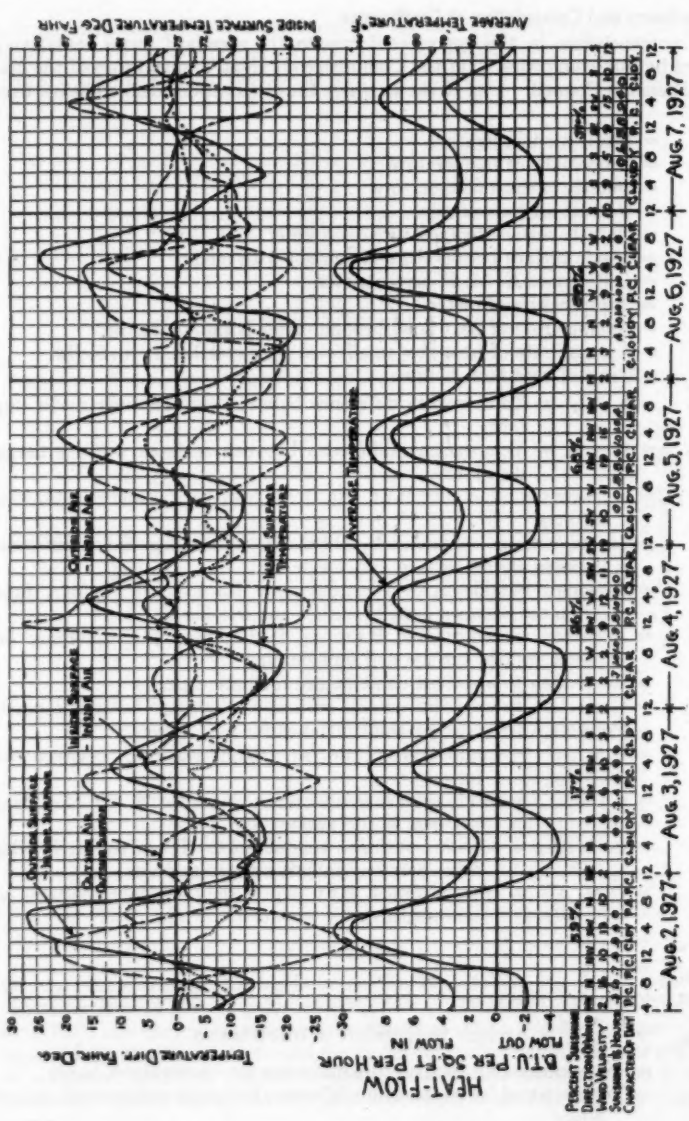

FIG. 8. LOG OF HEAT FLOW FOR SLAG-SURFACED ROOF

T_{h_i} = Time-interval for temperature difference for outside surface conductance, hours

T_U = Time-interval for temperature difference for transmittance, hours.

Referring to the curves for September 20, 1927 in Fig. 7, the total heat flow is represented by the lower shaded area, and the total temperature head or impulse is represented by the upper shaded area.

Total heat flow $H_m \times T_{H_m} = 44.67$ B.t.u./sq. ft.
Average rate of heat flow, $H_m = 4.70$ B.t.u./sq. ft./hr.
Total temperature head or impulse, $\Delta t_{1e} \times T_e = 169.3$ deg. hours
Average temperature head or impulse $\Delta t_{1e} = 23.5$ deg. fahr.

$\Delta t_{2e} = 26.3$

$$H_m = H_m \times \frac{\Delta t_{2e}}{\Delta t_{1e}} = 4.70 \times \frac{26.3}{23.5} = 5.26 \text{ B.t.u./sq. ft./hour}$$

$$C = \frac{H_m}{\Delta t_{2e}} = \frac{5.26}{26.3} = 0.20$$

$$h_i = \frac{H_m}{\Delta t_{h_i}} = \frac{5.26}{5.47} = 0.96$$

$$h_o = \frac{H_m}{\Delta t_{h_o}} = \frac{5.26}{-16.3} = -0.32$$

$$U = \frac{H_m}{\Delta t_U} = \frac{5.26}{6.11} = 0.86$$

R_e = Correction factor for heat capacity

Δt_m = Change in average temperature of roof

$R_e \times \Delta t_m = 13.62$ B.t.u./sq. ft.

$$\Delta C = \frac{R_e \times \Delta t_m}{\Delta t_e \times T_e} = \frac{13.62}{169.3} = 0.08$$

$$\Delta h_o = \frac{R_e \times \Delta t_m}{\Delta t_{h_o} \times T_{h_o}} = \frac{13.62}{-217} = -0.06$$

$$\Delta U = \frac{R_e \times \Delta t_m}{\Delta t_U \times T_U} = \frac{13.62}{38.5} = 0.35$$

$C = C + \Delta C = 0.20 + 0.08 = 0.28$ B.t.u./sq. ft./hr./deg. fahr. surface to surface

$h_i = h_i = 0.96$ B.t.u./sq. ft./hr./deg. fahr. surface to air

$h_o = h_o + \Delta h_o = -0.32 - 0.06 = -0.38$ B.t.u./sq. ft./hr./deg. fahr. surface to air

$U = U + \Delta U = 0.86 + 0.35 = 1.21$ B.t.u./sq. ft./hr./deg. fahr. air to air

Heat Flow Coefficients

Table 1 gives the results of the study made of the heat flow through two sections of concrete tile roof. Results for flow inward during the day and outward during the night are given separately. Tables 2 and 3 give similar data for the slag-surfaced and cinder-fill roofs.

For the concrete tile roof, the corrected values of C are in very close agreement; except for the values found prior to September 19 when the roof was wet, all values

of C give an average of 0.32. The corrected values of C for the slag-surfaced roof give an average of 0.38.

The inside surface conductance coefficient, h_i, from day to day, shows a greater variation, since smaller temperature differences and greater variation in conditions due to air motion are involved. There seems to be a difference in magnitude of the values obtained for day and night. When the heat is flowing inward and downward from the surface to the air, h_i is somewhat smaller than is the case when the transfer is upward from air to surface.

The inside surface conductances for the concrete tile roof were found to be 1.13 at

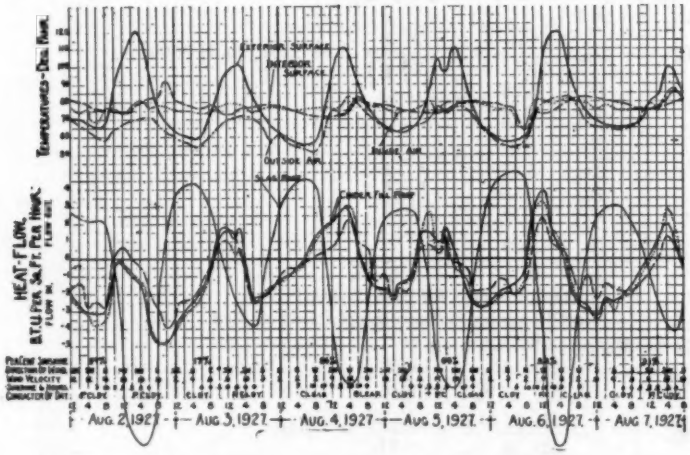

FIG. 9. LOG OF HEAT FLOW FOR CINDER-FILL ROOF

night and 0.91 during the day. The cinder-fill roof shows a similar difference in these surface conductances for night and day. The average values of h_i for the three roof sections are 0.47 for the day when heat was flowing in and 0.95 for the night when heat was flowing out.

The results from the slag-surfaced roof do not show this marked effect. The inside surface conductance is practically the same for both day and night when the values obtained were 1.52 and 1.49 B.t.u./sq. ft./hour/deg. fahr. from surface to air.

There was less air motion during the tests on the concrete tile roof than during the tests of the slag and cinder-fill roofs.

The inside surface of the concrete tile roof was newly planed yellow pine unpainted, that of the slag-surfaced was grey painted planed wood, and the cinder-fill was white painted concrete which was exceptionally white and clean. The data include a few high values of h_i.

If averages are accepted for values obtained at night when heat was flowing upward from the air to the surface then the values of h_i for the new planed yellow pine in the concrete tile roof, the grey painted wood in the slag-surfaced roof, and the clean white painted concrete in the cinder-fill roof are 1.13, 1.49 and 0.95 B.t.u./sq. ft./hour/deg. fahr. In THE GUIDE the surface conductance coefficients are given as 1.40 for wood and 0.93 for concrete, which values were probably determined for a

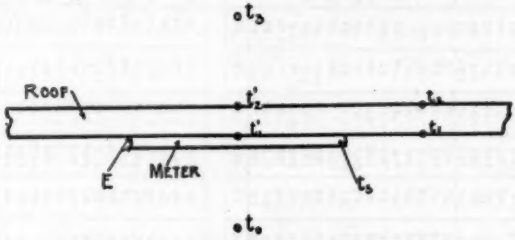

FIG. 10. APPLICATION OF HEAT METER

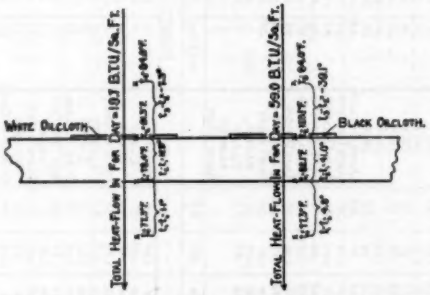

FIG. 11. HEAT FLOW THROUGH CONCRETE TILE ROOF COVERED WITH BLACK AND WHITE OILCLOTH

vertical wall where convection currents are much more effective in removing heat. It might be expected that values for a horizontal surface, such as the under side of the roof, would be less than for the same type of vertical surface. Again THE GUIDE does not give inside surface conductances for painted surfaces which no doubt depend more upon the surface of the paint than what is under the paint.

It would seem, therefore, that the values of 1.49 and 0.95 found for the horizontal surfaces of the dark grey painted wood in the slag-surfaced roof, and the white painted concrete in the cinder-fill roof should be accepted together with the 1.13 for the newly planed wood surfaces in the concrete tile roof.

It will be observed that values for outside surface conductances as found in Tables 1, 2, and 3 are very erratic for all types of roof tested. All day and night

values for the concrete tile roof, most values for the slag-surfaced roof, and all values obtained during the day in the cinder-fill roof are negative. That is to say,

TABLE 1. HEAT TRANSFER COEFFICIENTS FOR CONCRETE TILE ROOF

FIRST ROOF SECTION — SUMMER 1927 — SECOND ROOF SECTION

DAY	C_i	ΔC	C	t_a	h_o	h_i	v	CONDITIONS	DAY	C_i	ΔC	C	t_a	h_o	h_i	v	CONDITIONS
SEPT. 14	.27	.06	.33	52.3	-.39	1.02	.75	DRY	SEPT. 14	.26	.08	.34	51.0	-.22	.46	1.21	WET
" 15	.27	.06	.33	55.3	-.31	.91	.60	DRY	" 15	.29	.08	.37	78.5	-.27	.45	.48	WET
" 16	.23	.12	.35	57.8	-.39	1.00	1.17	WET	" 16	.20	.12	.32	83.7	-.48	.54	.43	WET
" 17	.23	.08	.31	61.4	-.38	1.07	.53	WET	" 17	.14	.08	.22	78.1	-.84	1.05	.65	WET
" 18	.19	.06	.25	77.2	-.57	2.80	1.19	WET	" 18	.13	.06	.19	72.5	-1.19	.58	.93	WET
" 19	.24	.04	.28	82.2	-.27	.97	1.21	DRY	" 19	.24	.04	.28	72.5	-.35	.38	1.17	DRY
" 20	.26	.04	.30	82.4	-.38	1.24	.84	DRY	" 20	.16	.04	.20	77.0	-.36	.87	.71	DRY
" 21	.24	.04	.28	82.6	-.37	1.24	.69	DRY	" 21	.21	.04	.25	77.0	-.33	.76	1.02	DRY
" 22	.23	.04	.27	81.2	-.33	.99	.63	DRY	" 22	.21	.04	.25	77.6	-.34	.67	.97	DRY
" 23	.22	.04	.26	81.2	-.33	1.03	1.21	DRY	" 23	.21	.04	.25	76.4	-.43	.97	1.09	PLAIN ROOF
" 24	.22	.04	.26	80.2	-.32	1.04	.81	WHITE, OKLEOTH	" 24	.21	.04	.25	76.4	-.43	.97	.69	PLAIN ROOF
" 25	.23	.04	.27	85.5	-.43	.80	.41	BLACK, OKLEOTH	" 25	.21	.04	.25	73.8	-.43	.97	.35	WHITE, OKLEOTH
" 26	.23	.04	.27	81.3	-.38	.92	.19	WHITE, OKLEOTH	" 26	.22	.04	.26	81.2	-.57	.77	.43	BLACK, OKLEOTH
" 27	.23	.04	.27	79.3	-.42	1.16	.77	DULL BLACK	" 27	.21	.04	.25	80.5	-.57	.88	.65	PLAIN ROOF
" 28	.24	.04	.28	78.7	-.42	.77	.84	DULL BLACK	" 28	.22	.04	.26	77.1	-.57	1.08	.85	SHINY BLACK
" 29	.24	.04	.28	76.9	-.46	1.01	.35	SHINY WHITE	" 29	.22	.04	.26	78.5	-.53	1.15	1.07	PLAIN ROOF
OCT. 1	.23	.04	.27	81.1	-.33	1.04	.91	CLEAR	OCT. 1	.22	.04	.26	78.1	-.50	1.15	1.04	SHINY BLACK
" 2	.19	.04	.23	84.3	-.26	.97	1.33	CLEAR	" 2	.20	.04	.24	79.8	-.31	1.17	2.96	CLEAR
" 3	.14	.04	.18	78.4				CLOUDY	" 3	.11	.04	.15	77.2	-.44	.72	.40	CLEAR
" 4	.14	.04	.18	65.7				PARTLY CLOUDY	" 4	.22	.04	.26	73.0	-.26	.45	1.64	CLOUDY
AVERAGE	.24	.05	.32	76.8	-.36	.84	.85		AVERAGE	.19	.05	.24	73.0	-.53	.88	.98	PT. CLDY
NIGHT									NIGHT								
SEPT. 14	.20	.06	.26	72.8	-.41	1.33	.50	PARTLY CLDY.	SEPT. 14	.27	.05	.32	81.3	-.53	1.15	.18	PARTLY CLDY
" 15	.20	.08	.28	73.4	-.48	1.38	.31	CLEAR.	" 15	.30	.02	.32	76.9	-.2.37	.59	.22	CLEAR.
" 16	.22	.08	.30	68.0	-.70	.97	2.15	CLEAR.	" 16	.26	.02	.28	68.0	-.1.53	1.02	.19	CLEAR.
" 17	.22	.08	.30	72.5	-.68	1.28	.34	PARTLY CLOUDY	" 17	.23	.02	.25	71.0	-..44	1.45	.32	PARTLY CLDY
" 18	.17	.05	.22	65.5	-.1.19	1.07	.25	CLOUDY —	" 18	.28	.02	.30	64.7	-..35	1.03	.30	CLOUDY —
" 19	.20	.04	.24	68.7	-..76	1.32	.37	CLEAR.	" 19	.28	.04	.32	64.3	-..63	.96	.43	CLEAR.
" 20	.20	.04	.24	70.4	-.1.19	1.26	.37	CLDY. TO CLEAR.	" 20	.28	.04	.32	62.6	-.1.67	1.23	.30	CLDY. TO CLEAR.
" 21	.21	.04	.25	70.3	-..64	1.20	.34	FAST PART. CLDY.	" 21	.31	.04	.35	61.7	-..82	1.23	.34	FAST PART. CLDY
" 22	.21	.04	.25	67.2	-.1.19	1.12	.37	CLOUDY	" 22	.27	.04	.31	62.6	-.1.08	1.08	.36	CLOUDY
" 23	.21	.04	.25	67.2	-..97	1.12	.57	CLDY. TO CLEAR.	" 23	.27	.04	.31	62.6	-..76	1.37	.77	CLDY. TO CLEAR.
" 24	.21	.04	.25	66.5	-..97	1.12	.50	CLEAR.	" 24	.24	.04	.28	61.8	-..59	1.37	.75	CLEAR.
" 25	.21	.04	.25	66.0	-..76	1.28	.40	CLEAR, P. CLOUDY	" 25	.21	.04	.25	57.8	-..74	1.06	.75	CLEAR, P. CLOUDY
" 26	.21	.04	.25	66.3	-.1.32	.83	.37	CLEAR, P. CLOUDY	" 26	.24	.04	.28	62.9	-..92	1.23	.25	CLEAR, P. CLDY.
" 27	.18	.04	.22	66.9		.83	.34	CLDY. TO P. CLDY.	" 27	.21	.04	.25	67.0	-..82	.96	.46	CLDY. TO P. CLDY
" 28	.19	.04	.23	64.5	-.1.08	.94	.34	CLDY.	" 28	.21	.04	.25	66.1	-..89	1.15	.15	CLDY.
" 29	.23	.12	.35	65.3	-..50	.94	.31	CLOUDY	" 29	.21	.04	.25	65.9	-.1.00	1.40	.40	CLOUDY
OCT. 1	.22	.08	.30	67.9	-..67	1.02	.36	CLEAR.	OCT. 1	.20	.04	.24	69.2	-.1.44	1.53	.33	CLEAR.
" 2	.19	.14	.33	73.3	-.1.48	.81	.76	CLEAR.	" 2	.20	.10	.30	73.2	-..76	1.32	.25	CLEAR.
" 3	.19	.14	.33	73.0	-..32	.76	.61	CLOUDY	" 3	.22	.04	.26	71.3	-..44	1.30	.17	QUART. CLDY
" 4	.16	.08	.24	64.4					" 4	.31	.04	.34	63.3	-..89	1.49	.39	CLOUDY
AVERAGE	.24	.05	.33	68.0	-..86	1.03	.59		AVERAGE	.24	.05	.32	68.7	-..78	1.23	.38	

heat was transmitted to the surface of the roof from the sun which caused the surface to be at a temperature higher than the air above through which the heat had to pass. This is due to the fact that heat from the sun is transmitted largely

by radiation which does not greatly warm the air but does warm an absorbing roof surface. Of the heat which the roof receives by radiation some is given back to the air and the remainder is transmitted through the roof.

Although negative outside surface conductances, h_o, were to be expected during the day, it seemed paradoxical to find the same true at night. The negative value of h_o found at night must be due to the surface of the roof losing heat to the sky or interstellar space at a greater rate than it is received by transmission through the roof from below. As a result, the temperature of the exterior surface falls below that of the air above. For a roof with high heat capacity, like the cinder-fill roof, the temperature of the roof surface does not fall below that of the air over it for a

TABLE 2. HEAT TRANSFER COEFFICIENTS FOR SLAG-SURFACED ROOF

DAY	C_1	Δc	c	t_m	h_o	h_i	U	CONDITIONS
AUG 1	.27	.07	.34	89.1°F	-.31		-1.30	PART CLOUDY
" 2	.37	.06	43	91.9	-.44		-1.16	PART CLOUDY
" 3	28	.06	.34	86.2	-.31	1.36	-.75	CLOUDY
" 4	.28	.06	.34	88.3	-.37	1.88	-8.72	CLEAR
" 5	.37	.05	42	88.8	-.40	1.74	-1.09	PART CLOUDY
" 6	.31	.06	.37	95.8	-.65	1.15	-2.43	PART CLOUDY
" 7	27	.09	.36	85.6	-.48		-4.12	CLOUDY
" 8	.31	.11	42	82.6	-.29			CLOUDY
" 9	.31	.06	.37	90.3	-.27	1.49	-1.80	CLEAR
" 10	.36	.07	.43	99.0	-.37	1.46	-.81	PART CLOUDY
" 11	.31	.07	.38	90.9	-.42	.58		PART CLOUDY
" 12	.31	.06	.37	99.2	-.38	1.71	-1.93	CLOUDY
" 13	.30	.10	40	91.1	-.49	2.34		CLOUDY
AVERAGE	.31	.07	.38	90.7	-.40	1.52	-2.38	
NIGHT								
AUG. 1	.29	.10	.39	68.5	-2.30	1.18	+.40	PART CLOUDY
" 2	.30	.09	.39	63.8	-1.48	1.66	.35	PART CLOUDY
" 3	.36	.06	.42	73.5	-5.49	1.45	.34	PART CLOUDY
" 4	.23	.09	.32	65.2		1.59	.45	PART CLOUDY
" 5	.32	.04	36	61.4	-4.14		.37	PART CLOUDY
" 6	.31	.07	.38	66.9	-1.60	1.08	2.37	PART CLOUDY
" 7	.28	.08	.36	72.6	-1.53	1.35	.44	CLOUDY
" 8	.31	.09	.40	84.1	-.57	1.34	.10	CLOUDY
" 9	.27	.07	.34	59.3	-2.69	.87	.29	CLEAR
" 10	27	09	.36	65.1	-2.39	1.37	.32	PART CLOUDY
" 11	.35	.08	.43	61.5	-2.92	1.48	.34	PART CLOUDY
" 12	.32	.12	44	68.1		1.51	.43	CLOUDY
" 13	29	.10	.39	71.1	-2.53	1.25	.33	CLOUDY
AVERAGE	.30	.08	.38	67.8	-2.51	1.49	+.55	

sufficient part of the night to give a negative value. The observed positive value must, however, be reduced in magnitude due to radiation.

It is obvious that a correct outside surface conductance cannot be obtained under natural conditions in summer. It seems equally true, however, that true outside surface conductances obtained by elimination of such radiation can mean nothing when applied to a roof or other surface affected by such radiation.

Since transmittance, U, depends upon h_o, it likewise defies evaluating under conditions found in these tests.

Radiation from the Roof at Night

It is of interest to attempt an explanation of the negative exterior surface conductance coefficient found at night. Heat is flowing from the interior of the build-

TABLE 3. HEAT TRANSFER COEFFICIENTS FOR CINDER-FILL ROOF

SUMMER 1927.

FIRST ROOF SECTION.						SECOND ROOF SECTION.						THIRD ROOF SECTION.						
DAY	C_1	t_m	h_o	h_i	U	DAY	C_1	t_m	h_o	h_i	U	DAY	C_1	t_m	h_o	h_i	U	CONDITIONS
						AUG. 1	.13	88°F	-.34	.59	-2.03	AUG. 1	.09	97°F	-.07	.44	-.92	PART CLOUDY
						" 2	.11	89°F	-.32	.55	-.31	2	.07	89°F	-.05	.67	-.20	PART CLOUDY
AUG. 3	.08	84°F	-.06	+.35	-.14	" 3	.09	84°F	-.06	.45	-.15	3	.09	85°F	-.04	.22	-.15	CLOUDY
" 4	.09	80°F	-.11	+.81	-.34	" 4	.08	80°F	-.10	.76	-.31	4	.06	84°F	-.07	.43	-.46	CLEAR
" 5	.08	81°F	-.10	+.50	-.35	" 5	.08	81°F	-.10	.48	-.36	5	.07	85°F	-.06	.29	-.72	PART CLOUDY
" 6	.05	87°F	-.13	+.41	-.37	" 6	.07	87°F	-.17	.46	-.49	6	.05	94°F	-.08	.36	-.69	PART CLOUDY
" 7	.07	84°F	-.10	+.46		" 7	.08	84°F	-.12	.38	-1.29	7	.11	86°F	-.14	.40	-.20	CLOUDY
" 8	.05	81°F	-.09	+1.04	-.12	" 8	.06	81°F	-.10	.86	-.16	8	.05	79°F	-.11	.81	-.09	CLOUDY
" 9	.10	92°F	-.10	+.44	-.52	" 9	.11	92°F	-.10	.24	-1.46	9	.09	99°F	-.07	.13	-.48	CLEAR
" 10	.07	94°F	-.07	+.41	-.44	" 10	.08	94°F	-.07	.46	-.48	10	.08	98°F	-.04	.31	-.57	PART CLOUDY
" 11	.05	86°F	-.07	+.64		" 11	.05	86°F	-.06	.61		11	.05	86°F	-.04	.26		PART CLOUDY
" 12	.03	90°F	-.04	+.38	-.36	" 12	.06	90°F	-.07	.36	-.78	12	.04	80°F	-.05	.32		CLOUDY
" 13	.07	86°F	-.08	+.34	-.71	" 13	.10	86°F	-.08	.36	-.68	13	.10	88°F	-.14	.29	-1.98	CLOUDY
AVERAGE	.07	86°F	-.09	+.53	-.37	AVERAGE	.08	86°F	-.13	.49	-.70	AVERAGE	.07	88°F	-.07	.39	-.59	
NIGHT						NIGHT						NIGHT						
						AUG. 1	.03	78°F	+.01	.92	+.03	AUG. 1	.07	78°F	+.06	.42	+.08	PART CLOUDY
AUG. 3	.14	73°F	+.22	+.68	+.12	" 2	.09	75°F	+.19	.71	.12	2	.03	80°F	-.03	.39	.04	PART CLOUDY
" 4	.13	72°F		.88	.15	" 3	.13	73°F	+.21	.72	.11	3	.06	74°F	.10	.71	.05	PART CLOUDY
" 5	.12	71°F	.35	1.36	.13	" 4	.11	72°F	+.38	.79	.12	4	.07	73°F	.19	.74	.07	PART CLOUDY
" 6	.13	77°F	.32	.61	.20	" 5	.14	71°F	+.40	1.37	.15	5	.08	73°F	.14	.59	.12	PART CLOUDY
" 7		78°F	1.14	.68	.32	" 6	.11	77°F	+.26	.80	.17	6	.07	77°F	.15	.43	.10	PART CLOUDY
" 8	.09	72°F	.49	1.64	.09	" 7	.20	78°F	+.93		.26	7	.14	77°F	.43	1.02	.15	CLOUDY
" 9	.07	75°F	.14	1.07	.10	" 8	.05	72°F	+.24		.05	8	.01	76°F	.03	.31	.02	CLOUDY
" 10	.10	80°F	.19	1.32	.10	" 9	.07	75°F	+.16	1.08	.10	9	.05	76°F	.08	.91	.06	CLEAR
" 11	.17	71°F	1.26		.14	" 10	.08	80°F	+.15	1.45	.08	10	.03	79°F	.06	.77	.03	PART CLOUDY
" 12	.13	75°F	1.30	.76	.11	" 11	.16	71°F	+.12		.13	11	.11	86°F	.21	.59	.12	PART CLOUDY
" 13		77°F		1.74		" 12	.14	73°F	+.32	1.54	.11	12	.09	77°F	.21	1.13	.07	CLOUDY
						" 13		77°F	+.36		.16	13	.12	78°F	.36	1.79	.08	CLOUDY
AVERAGE	.12	75°F	+.60	+1.07	+.15	AVERAGE	.11	75°F	+.28	1.04	+.12	AVERAGE	.07	77°F	+.22	.75	+.06	

ing to the outside, and is dissipated to or through the air above. The roof surface becomes cooler than the outside air, making the exterior surface conductance as measured, negative. The apparent paradox is the loss of heat from the exterior surface to or through air which is at a higher temperature. This is due to radiation of heat from the roof surface to interstellar space. The factor effecting this transfer is the difference between the fourth powers of the absolute temperatures of the roof surface and the sky which is generally assumed to be absolute zero.

In reverting to the C. G. S. system of units which is more convenient for dealing with radiant energy, it is found that 1 B.t.u./sq. ft./hour is equal to 0.0000754 calories/sq. cm./second. For the concrete tile the maximum heat flow through the

TABLE 4. COMPARISON OF THE EFFECTS OF BLACK AND WHITE OILCLOTH ON HEAT FLOW. CONCRETE TILE ROOF

CONCRETE TILE ROOF 1927								
DAY	SEPT. 24		SEPT. 25		SEPT. 27		SEPT. 28	
METER NO.	12	13	12	13	12	13	12	13
	BLACK OILCLOTH	PLAIN ROOF	BLACK OILCLOTH	WHITE OILCLOTH	WHITE OILCLOTH	PLAIN ROOF	DULL BLACK OILCLOTH	SHINY BLACK OILCLOTH
TOTAL HEAT-FLOW B.T.U. PER SQ. FT.	52.0	38.7	59.0	19.7	23.1	41.7	26.1	23.0
MAX. HEAT-FLOW B.T.U. PER SQ. FT./HR.	6.4	9.0	10.1	4.6	4.4	10.1	4.2	3.6
MAX. OUTSIDE SURFACE TEMP. °F	108.6	109.2	123.1	91.3	92.6	123.0	98.7	99.5
MAX. INSIDE SURFACE TEMP. °F	75.2	73.9	82.1	78.4	83.1	83.8	80.4	81.0
PERCENT SUNSHINE	61%		63%		65%		51%	
NIGHT								
TOTAL HEAT-FLOW B.T.U. PER SQ. FT.	16.6	23.0	22.0	20.0	10.6	17.0	12.1	13.3
MAX. HEAT-FLOW B.T.U. PER SQ. FT./HR.	-2.0	-2.2	-2.0	-1.0	-1.2	-1.7	-1.3	-1.4
MIN. OUTSIDE SURFACE TEMP. °F.	45.7	42.3	45.3	44.6	59.0	58.0	60.4	60.1
MIN. INSIDE SURFACE TEMP. °F	52.4	52.6	53.8	54.2	64.6	64.0	63.5	63.5

roof at night was 4 B.t.u./sq. ft./hour. Since the outside surface of the roof was cooler than the air above, heat was at the same time flowing to the surface from the air at a rate equal to about 3.08 times the temperature difference between the air and the surface which was about 5 deg. fahr. This gives a heat flow to the roof from the air of 15.4 B.t.u./sq. ft./hour and a total loss by radiation to space of 19.4 B.t.u./sq. ft./hour or 0.00146 calories/sq. cm./sec. The simple radiation formula $H = \frac{c}{J} \times A \times \sigma \times t \, (\theta_1 - \theta_2)$ was used to compute the heat lost by radiation.

H = heat radiated in calories
c = radiation constant $= 5.72 \times 10^{-5}$ ergs/sec./cm.^{2}/$(\theta_1^4 - \theta_2^4)$
σ = emissivity. In this case equal about 0.5
A = area in cm.^{2} = 1
t = time in seconds = 1
J = 4.183×10^7

Θ_1 = absolute temperature of roof surface deg. cent.
Θ_2 = absolute temperature of space

Under the condition of the test the temperature of the surface Θ_1 was about 50

TABLE 5. EFFECT OF SPRINKLING ON HEAT FLOW THROUGH CONCRETE TILE ROOF

	CONCRETE TILE ROOF			
	SEPT. 14, 1927. DAY		SEPT. 15, 1927. DAY	
	DRY	WET	DRY	WET
TOTAL HEAT FLOW	36.50	3.60	58.50	3.70
MAXIMUM HEAT FLOW	6.50	1.90	9.10	1.30
MAXIMUM OUTSIDE SURFACE TEMPERATURE	109°F	86°F	133°F	85°F
MAXIMUM INSIDE SURFACE TEMPERATURE	88°F	80°F	98°F	84°F
MAXIMUM INSIDE AIR TEMPERATURE	84°F	84°F	89°F	89°F
MAXIMUM OUTSIDE AIR TEMPERATURE	87°F	87°F	91°F	91°F
RELATIVE HUMIDITY	99		70	
PERCENT SUNSHINE	60% SUN		100% SUN	
CHARACTER OF DAY	CLOUDY		CLEAR	
	NIGHT		NIGHT	
TOTAL HEAT FLOW	-14.8	-19.8	-17.8	-31.6
MAXIMUM HEAT FLOW	- 1.4	- 1.6	-1.8	- 2.1
MINIMUM OUTSIDE SURFACE TEMPERATURE	67°F	69°F	73°F	68°F
MINIMUM INSIDE SURFACE TEMPERATURE	73°F	73°F	73°F	75°F
MINIMUM INSIDE AIR TEMPERATURE	73°F	73°F	76°F	76°F
MINIMUM OUTSIDE AIR TEMPERATURE	74°F	74°F	70°F	70°F
RELATIVE HUMIDITY	69		66	
CHARACTER OF DAY	PARTLY CLOUDY		CLEAR	
NET HEAT FLOW FOR APPROXIMATELY 24 HRS.	+21.7	- 16.0	+40.7	- 28.1
RATE OF SPRINKLING	0.05 GAL./SQ. FT./HR.			

deg. fahr. or 283 deg. cent. absolute. The temperature of interstellar space Θ_2 is generally assumed to be absolute zero with a clear sky. Hence,

$$H = \frac{5.72 \times 10^{-5}}{4.183 \times 10^{7}} \times 0.5 \times 1 \times 1 \,(283^4 - \Theta^4)$$
$$= 1.367 \times 10^{-12} \times 0.5 \times 7.214 \times 10^9$$
$$= 4.93 \times 10^{-3} \text{ or } 0.00493 \text{ calories/cm.}^2\text{/sec.}$$

or the theoretical loss based upon the above assumption is between two and three times the actual loss. This difference can easily be taken care of by error in the assumption of absolute zero for the sky, and by the fact that the sky was not entirely visible due to intervening buildings and other obstructions. It would seem, therefore, that radiation may account for the negative surface conductance found.

Effect of Surface Color on Heat Absorption and Transfer

The curves in Fig. 6 and the values in Table 4 illustrate the differences in heat flow through the cement tile roof when different colored coverings are placed

thereon. Weather and test results limit the results for comparison to September 24 to 28. On September 26 the position of the black and the white oilcloth were to be interchanged early in the morning. Due to the misunderstanding, the observer did not make the change until late in the forenoon, after a large part of the sun's effect had already been felt.

The data for September 24 are not convincing as to whether the plain roof or the roof covered with black oilcloth absorbs more heat. The maximum rate of absorption is unquestionably higher for the plain roof. The total heat flow for the

TABLE 6. COMPARISON OF MEASURED AND COMPUTED MAXIMUM AND TOTAL HEAT-FLOWS—CONCRETE TILE ROOF

CONCRETE TILE ROOF - W.A. BODE CO.

A	C - CONDUCTANCE B.T.U./SQ.FT./HR./°F. B	MAX. MEASURED HEAT-FLOW B.T.U./SQ.FT./HR. C	MAX. COMPUTED HEAT-FLOW B.T.U./SQ.FT./HR D	TOTAL HEAT-FLOW MEASURED DURING DAY B.T.U. PER SQ.FT. E	TOTAL HEAT-FLOW * COMPUTED DURING DAY B.T.U. PER SQ.FT. F
SEPT. 19, 1927	.31	4.9	6.6	27.8	66.0
20		8.3	12.3	44.7	123.
21		7.9	9.9	41.0	99.0
22		9.3	12.3	40.0	123.0
23		5.1	8.2	22.8	82.0
24		8.4	11.2	52.0	112.0
25		10.1	12.9	59.0	129.0
26		6.4	10.2	38.5	102.0
27		4.4	4.0	23.1	40.0
28		4.2	6.0	26.1	60.0
29		3.2	4.2	17.6	42.0
30		2.0	1.9	10.7	19.0
OCT 1, 1927		10.2	12.0	54.7	120.0
2		8.3	10.7	42.7	107.0
3		0.9	2.7	2.5	27.0

* OBTAINED FROM THE PRODUCT OF -
CONDUCTANCE X MAX TEMP DIFF. X 10 HRS.
SINCE HEAT IS CONSIDERED FLOWING IN
DURING TEN HOURS EVERY DAY

day, however, is greater in the case of the black covered roof. There is no available explanation for the conflicting evidence. It should be noted that the addition of the black oilcloth adds to the insulation of the roof besides its possible effect in increasing heat absorption at the surface.

Table 4 indicates that the maximum temperature of the roof surface under the black oilcloth was a little lower than the maximum surface temperature of the bare roof.

The curves in Fig. 6 and the data in Table 4 show very strikingly the relative absorption of the black and the white oilcloth. This comparison is made perhaps more strikingly in the diagrammatic sketch, Fig. 11. Not only is the heat flow from the sun to the surface of the roof under the black oilcloth more than double the flow through the white oilcloth, but this greater flow through the black oilcloth takes

place to a surface which was 32 deg. higher than that of the surface under the white oilcloth; the maximum temperature of the surface under the black oilcloth being 123 deg. fahr. while that under the white oilcloth was only 91 deg. fahr. The temperature drop through the roof itself is about proportional to the flow, being 13 deg. under the white oilcloth, and 41 deg. under the black, giving maximum inside surface temperatures of 82 deg. fahr. and 78 deg. fahr. under the black and the white oilcloth, respectively.

It will be further observed from the curves of Fig. 6 that during a considerable part of the day heat was flowing out through the white oilcloth while it was flowing in through the black oilcloth only a few feet distant.

What effect the application of the white oilcloth to the entire roof would have upon the temperature within cannot accurately be predicted from the data available.

The data for September 27 shows a comparison of flow through the plain roof and the roof covered with white oilcloth. The white oilcloth considerably reduces the flow from that passing through the plain roof, and the data for this day taken in comparison with that of September 24 prove that the plain roof acts in its radiation absorption qualities much more nearly like the black than it did like the white oilcloth. A good reflector is a poor radiation absorber.

The data for September 28 show the comparison of absorbing qualities of dull black and shiny black oilcloth, the dull black showing greater absorption than the shiny black covering.

The effect of the colors upon heat loss at night is not as pronounced as their effect on adsorption during the day. This is largely due to the total rate of heat transfer not being as great at night as during the day. The data for September 25, however, indicate rather clearly that the black surface loses heat to space more rapidly at night than does the white which is in agreement with the recognized physical law that a good radiation absorber is also a good radiation emitter.

Effect of Sprinkling on Heat Absorption by and Transmission through a Roof

The curves in Fig. 5 and the data in Table 5 show the very great effect which sprinkling can have on heat absorption by and transmission through a roof.

On September 14, 15, 16 and 18 a section of roof over one of the meters was sprinkled. On September 18 the entire roof was sprinkled and it was hoped that information could be gathered on the resultant temperature in the building. A marked change in weather and a shower of rain made such a comparison impossible, and unfortunately it was not possible to repeat the test later. The study, therefore, only avails information on the relative rate of heat absorption and transmission. The resultant inside temperature due to sprinkling the entire roof can only be had therefrom by deduction.

The curves in Fig. 5 show very strikingly the effect of sprinkling on the maximum rate of flow and on the total heat flow through the roof. Table 5 gives a direct comparison of numerical values for September 14 and 15. September 14 was cooler than the 15th, the air temperature being only 89 deg. fahr. on the former and 91 deg. on the latter date. The relative humidity on the 15th was, however, much lower.

The total heat flow into the building through the dry roof was 36.5 B.t.u./sq. ft. on the 14th and 58.5 B.t.u./sq. ft. on the 15th. Through the wet roof the total

heat flow was 3.8 and 3.7 B.t.u./sq. ft. for these two days. The maximum rate of flow gives a similar comparison. The fact that while the heat flow through the dry roof responded to the higher temperature on the 15th, while the heat flow through the wet roof was actually lower on the warmer day, is very striking, but can be explained by the fact that the relative humidity was lower on the hotter day resulting in the cooling of the wet roof by evaporation.

During the night when the heat flow was outward there was a greater rate of heat loss through the wet roof. The net effect for the 24-hour period was an inward flow of 21.7 and 40.7 B.t.u./sq. ft. for the 14th and 15th, respectively, for the dry roof, and an outward flow of 16 and 28 B.t.u./sq. ft. for these two days through the wet roof.

A comparison of the maximum inside surface temperature under the dry and sprinkled sections is the best index of the effect of sprinkling on resulting inside temperature. On the 15th the maximum inside surface temperature under the dry section of roof was 95 deg. fahr. and that under the sprinkled section 84 deg. fahr.

While there may be much objection to cooling a building in summer by sprinkling a roof, these results indicate considerable possibility in this direction.

On the 15th, 58.5 B.t.u./sq. ft. flowed in through the dry roof during approximately 10 hours while only 3.7 B.t.u./sq. ft. flowed in through the wet roof.

In reality there was an actual resultant outflow of 54.8 B.t.u. during this 10 hours. Accepting 3.7 as the inflow during the 10-hour period, the reduction by sprinkling was 54.8 B.t.u./sq. ft. This was accomplished by the use of 0.50 gal. of water/sq. ft. for the 10-hour period, which could no doubt be reduced by efficient spray design. The cost of water for reducing heat flow into the building is $2.93 per million B.t.u. based upon water cost at 24 cents per 100 cu. ft. This may be compared with $1.25 per ton of refrigeration or $4.35 per million B.t.u. absorption in the building by mechanical refrigeration.

Application of Heat Transmission Coefficients

One must exercise caution in applying any accepted heat transmission constants for determining total heat flow over a period of time when temperature conditions are varying. This is especially true when one tries to calculate the probable heat absorption of a building over a period of time in summer when there is a rapid and wide variation in rate of flow from hour to hour. Table 6 helps to demonstrate some of the errors which one might make. Columns *B*, *C* and *E* give, respectively, the average conductance, the daily maximum rate of flow and the total daily flow through the concrete tile roof as measured during the test. Column *D* shows a computed maximum daily rate of flow as given by the product of the maximum difference and the accepted conductance. The computed value is almost always high. This is because the maximum flow lags behind the maximum temperature difference and never equals the value, which would occur were the maximum temperature difference maintained over an extended period. When a maximum temperature difference either in hot or cold weather is experienced for a short period of time the rate of heat gain or loss will never equal the value computed by multiplying the maximum temperature difference by the accepted coefficient.

Column *F* shows an error in calculating heat flow which is obvious but which is sometimes made. The heat flow over the 10-hour period (10 hours is found to be

approximately the time over which heat flows into a building on a hot summer day) is estimated by multiplying together the accepted conductance value, the maximum temperature difference and the number of hours over which flow is experienced. This value is always higher than the actual heat flow as measured experimentally and given in Column *E*.

Conclusions

1. Although there is considerable difficulty in evaluating heat transmission coefficients from data collected by the Nicholls' heat flow meter when temperature conditions fluctuate rapidly, some of the values can be satisfactorily determined.

(*a*) The inside surface conductances can be evaluated to as high a degree of accuracy as any accepted value can be applied.

(*b*) The conductance can be evaluated by correcting for the heat capacity of the roof in cases where the lag between maximum temperature difference and maximum heat flow is not greater than five hours.

(*c*) The outside surface conductance is found to be negative while the sun is shining in hot weather and is frequently negative during the night in summer. It is difficult, therefore, to evaluate this constant in summer, but it is equally true that any accepted value cannot be satisfactorily applied.

(*d*) Since transmittance, U, depends upon the outside surface conductance, there is the same difficulty in evaluating it from data collected in summer.

2. Heat absorbed by and transmitted through a roof can be considerably reduced by painting or covering the surface with a reflecting surface.

3. Heat absorption and flow through a roof can be greatly decreased by sprinkling the roof with water.

JOINT DISCUSSION

Coefficients of Heat Transfer as Measured under Natural Weather Conditions and Heat Transfer through Roofs under Summer Conditions

THOMAS CHESTER (WRITTEN): This paper on heat transfer through roofs under summer conditions is a very interesting paper and its authors are entitled to a great deal of credit for some painstaking work characteristic of the Research Laboratory.

The principal inference to be drawn from the paper is the great amount of solar heat transmitted through roof surfaces and the way in which this outstanding factor militating against comfort in summer has been generally disregarded.

Table 6 shows a measured inward heat flow slightly over 10 B.t.u. per square foot per hour on October 1, when the sun is considerably below its maximum rise above the horizon. The amount of heat received per square foot of horizontal roof surface per hour is probably directly proportional to the sine of the angle of the elevation of the sun. From this it is apparent that the heat received per square foot of roof surface per hour will be more than 10 B.t.u. on June 21 and also during

July, when the atmospheric temperature is high and less heat can be dissipated by convection to air flowing over the roof.

Fortunately for human comfort the force of gravity operates in our favor, as the air heated by contact with the interior roof surfaces will stratify and remain as far as possible above the floor level. In consequence this air should not be disturbed by any ventilating system to the extent of forcing it to a lower level, though it should be removed as rapidly as possible by roof ventilators or extraction fans.

The difference between the effects of black and white roof surfaces is indicated very strikingly on p. 429, the white showing a temperature reduction of 32 degrees for the roof surface under the oilcloth and this was during September.

From experiments made by others it has been shown that a one-story building painted black will reach an interior temperature as much as 35 degrees in excess of the same building painted white.

Investigations made by Dr. C. W. Graham to determine the effects of clothing of different types and colors showed that hottest is black cotton lining and the coolest is new white cotton drilling. The difference in temperatures of thermometers laid under these fabrics was 32.6 deg. in favor of the white material.

Very few concerns pay any attention to the matter of reducing solar heat received through roofs and walls but I do happen to know of a match factory at Wadsworth, O., a boiler plant at Beaver Falls, Pa., and an artificial silk mill at Cumberland, Md., where white oil paint and water resisting whitewash are used for this purpose.

The Research Laboratory should investigate this subject further as soon as convenient and get data on other types of roofs including a 2-in. plank roof with three-ply cover. The information so obtained should be summarized in tabular form for the convenient use of members of this Society.

LEE NUSBAUM (WRITTEN): The paper on heat transfer through roofs under summer conditions is a very interesting paper and bears out fully the writer's contention regarding the advantage of insulating all buildings whether factory or residence against heat and cold. There is no question about the savings to be obtained by so doing.

This paper brings out the fact that roofs even with a slightly better insulation retard the heat flow through the roof. An interesting point brought out also is the night heat flow outward through the roof; but this can be accounted for by the fact that the heat of the sun during the day has been conducted through the roof and into the roof space and at night time when the outside air is cooler the heat, naturally, in the roof space will flow out through the roof. If the roof was properly insulated the heat flow meter would show very little inflow in day time or outflow at night time. The temperature of the sun being so much greater than the surrounding atmosphere, the amount of heat flow would be much greater on a sunshiny day than a cloudy day.

The suggestion to decrease the heat flow by sprinkling the roof we consider a good one because of the existing consideration or where it would be impossible to insulate the roof, but the much better arrangement is to insulate the roof as there is only the first cost of insulation whereas the sprinkling of a roof involves continuous cost and is only a makeshift.

The paper is very instructive and interesting and to the writer's mind certainly brings forward more forcibly the idea of insulating buildings.

L. A. HARDING: I think the Society ought to express its thanks and appreciation to the Research Staff for these two fine papers. The paper presented on Heat Transfer through Roofs under Summer Conditions is a pioneer paper, the first, I believe, of its kind that has appeared before any engineering society, and it is particularly interesting to those engaged in air conditioning work. Those who are interested in this work should give this paper careful study. Several things will be found that will be helpful in calculating on the heat transfer through roofs in summer.

One thing which these tests have brought out is that if the heat capacity of the roof is large, it is perfectly safe to employ the usual methods of calculation.

The first paper that was presented, giving the comparisons of the computed and actual heat transmissions found on walls: the reason for that paper is this: about 15 years ago when we first started to present heat transmission data to this Society, said that was all right, but they wanted to take it with a grain of salt; college professors could do a lot of figuring and all that sort of thing, but we don't know whether the actual heat transmission of the wall is twenty-five hundredths or something else.

Those tests were run under considerable expense to this Society. We have spent perhaps more on heat transmission than on any other sort of problem. Now, we see the results of those tests, and how near the actual results are to those calculated. There are 18 tests, leaving out the concrete test, only two of which are very much different from the calculated amounts.

Now, it costs a lot of money to run these tests, and I, for one, am perfectly satisfied that the tests run in laboratories giving the conductivity of various materials is the proper method, and it is entirely unnecessary to spend more money checking the conductivity of materials in compound walls.

There is one bit of data we are short, and little work has been done for the past 13 years. That is surface factor data, and I think the Laboratory staff should do some work on that in the near future. These tests are quite as important as the conductivity tests.

H. P. REID: I didn't understand from Mr. Houghten what the reason was for the testing with a wet and dry roof, and why it was done on the tile roof and not done on the slag-filled roofs. He did remark that there was no effort made to control the rate of moisture or water flow on those roofs. Had there been such a control I think he would have found considerable difference. For instance, had that spray been so controlled that evaporation would have kept the roof dry he would have found under the sun conditions an outflow of heat from the building rather than inflow.

I have known of tests conducted in the tropics where the room was cooled below atmospheric temperature by controlling the spray rate on the roof to the rate of evaporation.

The second question I wish to ask is what was the significance of the white and

the black oilcloth? Was that looking forward to a possible painting or coating of the roof? If so, what type of paints would be suggested for further investigation?

Along that line I would like to suggest the investigation to go forward on any of these types of roof with aluminum paints. Not that I am in any way connected with any aluminum paints, excepting that we have found in much of our work that aluminum paints over metal shells will greatly reduce the heat transfer both ways.

Then, as to the slag-fill on the roof: I am not familiar with these roofs, but what type of slag was used for a fill? Was that an air-cooled slag, crushed, or was it a granulated slag, water-quenched? The granulated slag, water-quenched, is a much more effective insulator than the crushed slag.

L. L. LEWIS: I would like to add the deep appreciation of a man who has spent all of his life in air conditioning.

In air conditioning we have dealt very largely with the reverse of the heating problem. We have had to cool in summer and to absorb among other sources of heat, the heat coming from the sun. Just as the Research Bureau gave us the comfort chart, so they now have confirmed an experience of long standing that the actual coefficients did not indicate the actual rate of heat inflow.

We knew from tests that were made on systems that the actual inflow of heat from the sun was not as great as the calculations showed it should be. So we have followed our own empirical rules to apply some correcting factor for the heat capacity of the roof.

I have not had an opportunity to check back, but I know very well that Mr. Houghten has given us some data which will enable us to get very close to the actual conditions.

I would like to ask one question. Has any attempt been made to determine the effect of varying the temperature of the spray water? That may throw some light on an interesting problem as to the disposition of the water used for condensing in refrigerating installations. In some cases the water is purchased for condensing, and having been heated must be disposed of. We have had some little experience in installations of that kind, and believe that we have been gaining by wetting the roof with warmed water.

In another case the most convenient place for the cooling pond for condensing water is on the roof. There has been some question as to what temperatures could be reached before the water would heat, rather than to cool the roof.

F. C. HOUGHTEN: The filled roof reported was a cinder filled and not a slag filled construction. The slag roof consisted of tongue and groove sheathing covered with a roofing paper, tar and fine granular slag.

The real purpose of the investigation with the Nicholl's Heat Flow Meter was to develop heat transfer coefficients as reported in the paper, "Coefficients of Heat Transfer as Measured under Natural Weather Conditions." The reason for sprinkling roofs and covering them with surfaces of different color and reflecting power was to determine the magnitude of the effect on heat transfer and the possibility of decreasing heat flow into a building.

The water used in sprinkling was about 68 deg. and as pointed out in the paper,

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little effort was made to control the rate of sprinkling. As indicated by Mr. Reid the effect of rate of sprinkling may be important and under certain conditions greater cooling might be had by using less water. This, however, depends upon both the wet- and dry-bulb temperature of the air and the temperature of the water. If the air is very dry, as in arid districts of the West, the use of less water so that it will not drip off the roof might result in a temperature of the roof surface below that of either the air or the water used for sprinkling. The temperature of the surface of the roof would tend to fall to the wet-bulb temperature of the air. There is possibility of accomplishing a good deal through further study of the effect of methods of sprinkling a roof on maximum cooling and economy in use of water.

Black and white oilcloth were used as coverings in this study for the reason that an earlier investigation of the subject at Pittsburgh showed that they apparently gave the greatest contrast in reflecting heat. In an earlier laboratory report, there is some data on the relative effect of black and white oilcloth, black and white silk, aluminum painted surfaces and a bare slate roof. Aluminum paint was shown by these tests to greatly reduce the heat absorbed by a roof.

No. 811

HEAT TRANSMISSION RESEARCH

By F. B. ROWLEY[1] (*Member*), F. M. MORRIS[2] AND A. B. ALGREN[3] (*Non-Members*)

MINNEAPOLIS, MINN.

FOR several years past experimental work has been in progress in the Engineering Experiment Station at the University of Minnesota relative to the flow of heat through building and insulating materials. These experiments have been directed to the development of apparatus and the testing of built-up wall sections and insulating materials. Results have been published from time to time in the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS JOURNAL, and other technical papers as well as in Bulletin No. 3 of the Engineering Experiment Station.

During the past year this work has been conducted as a cooperative research project between the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the University of Minnesota, the expense being shared jointly by the two institutions. The object has been to refine the test methods; to make a more exhaustive series of tests covering both built-up wall sections and insulating materials, and to determine accurately the relation between the results obtained by different test methods.

There are at least three well known methods for determining heat transfer through materials, the hot plate method, the hot box method and the Nicholls Heat Meter. These methods need no extended discussion at this time as the basic principles of each are generally understood. Thus far this work has been confined to work with the hot plate and the hot box.

The fundamental difference between the constants derived by the two methods is that for those derived by the hot box method and the Nicholls Heat Meter, the so-called surface resistances of the materials are included; whereas in the hot plate constants they are eliminated. The first two being better adapted for determining the heat transmission through built-up wall sections and the hot plate for determining the conductivity of homogeneous materials. With a proper knowledge of

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The results of cooperative research between the University of Minnesota and the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

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surface constants for a material, it should be possible to calculate the transmission from air to air from the conductivity of the material or from the hot plate constant. Likewise the hot plate constant should be easily determined by the other methods providing the surface temperatures can be correctly taken. Formulae for the conversion from one constant to the others have been developed and

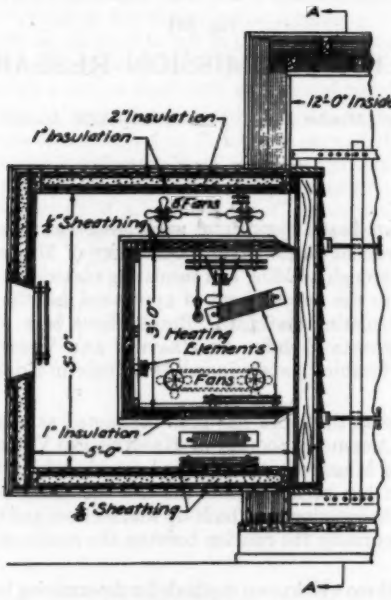


FIG. 1. SECTIONAL VIEW OF DOUBLE BOX AND WALL SECTION IN PLACE

are well known but in practice the application of these formulae do not always give comparable results. This disagreement seems to be due to the lack of knowledge of proper surface constants to be used in connection with the hot plate conductivities. Many variables enter into the problem and only by a careful control of these variables when the constants are derived can the results be applied with any degree of certainty.

With these general problems in view, a series of tests has been outlined with the following objectives:

a. To determine practical heat transmission constants for the different wall sections in common use

b. To determine the surface constants of materials under different conditions of surfaces, air temperature, air motion and width of air space

c. To work out the proper relation between the hot box and hot plate results, such that one may be derived from the other.

The series of walls to be tested includes frame construction, brick, tile and con-

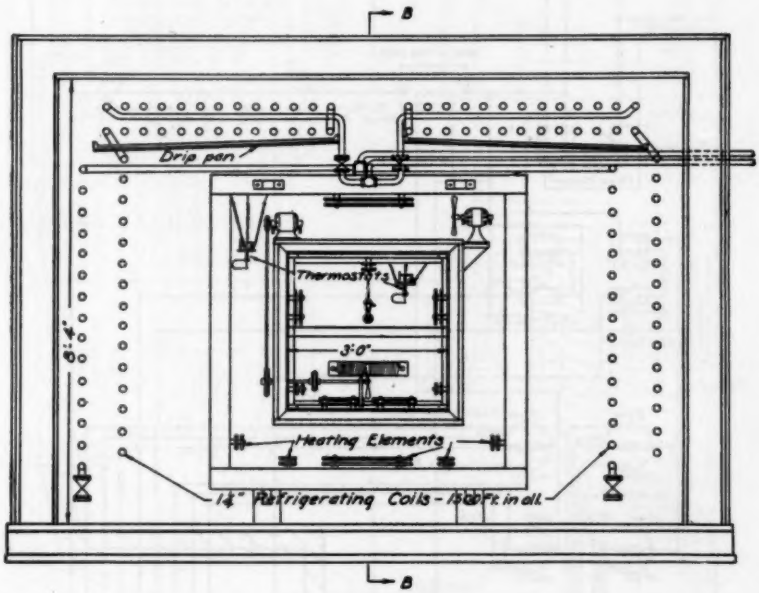


FIG. 2. SECTIONAL VIEW OF COLD ROOM LOOKING INTO OPEN END OF TEST BOX

crete both with and without insulation, the aim being to cover typical walls of each type.

Thus far tests have been conducted on something over twenty of those walls in common use and also many tests have been made on the common types of insulating materials. In making the wall tests, full data have been recorded concerning all materials used in the construction of the walls together with the hot plate constants for any insulating materials used. In several cases sufficient data have been taken to compare the constants determined by the hot plate method with those determined by the hot box method.

This paper is not intended as a complete report of the work as only part of it has been finished. Thus while the study of surface constants is in progress and some

of the results are reported here, the effect of wind velocity, thickness of air space and character of surface has yet not been determined.

In the tests which have been made covering insulated and non-insulated walls,

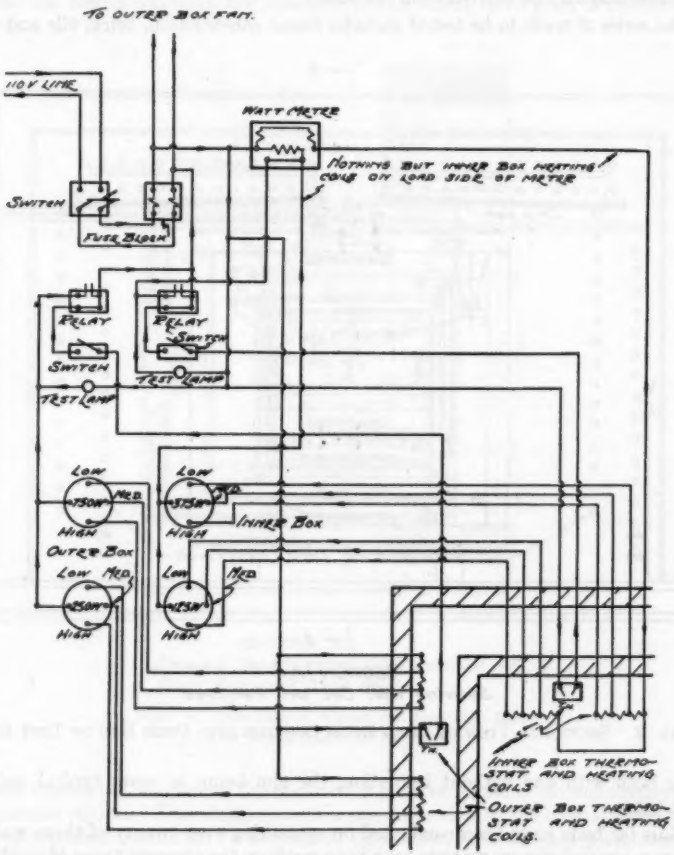


FIG. 3. DIAGRAM OF ELECTRICAL WIRING FOR HEATING ELEMENTS

it has not been the intention to compare different commercial insulating materials but rather to show what effect materials of given qualities will have on the thermal resistance of the wall. For this reason trade names have been omitted. In each case the material has been designated by a letter and classified as board, quilted, etc. The physical properties of the material are given as well as the insulating

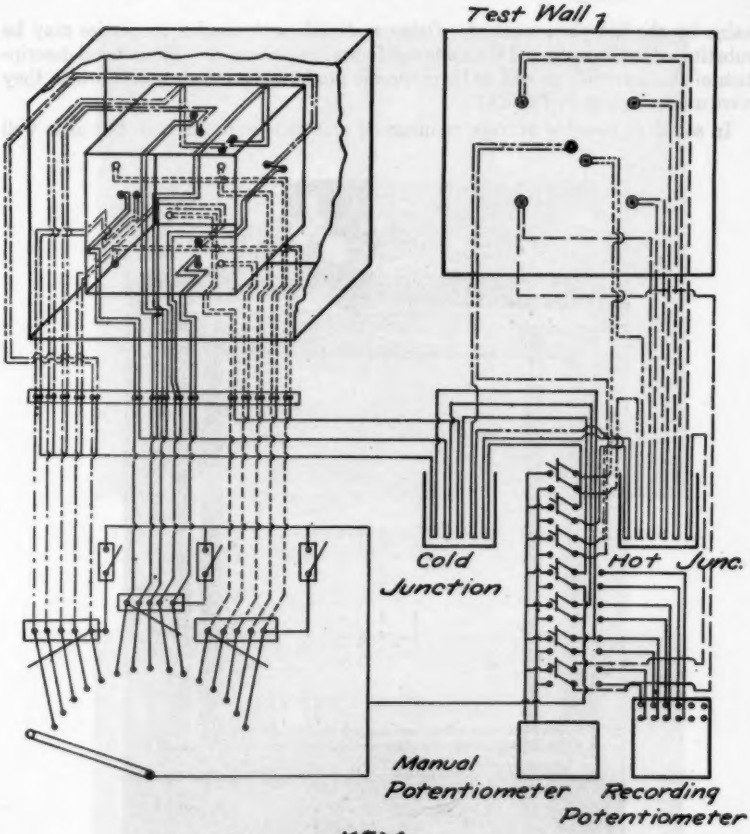

Test Wall 7
Cold Junction
Hot Junc.
Manual Potentiometer
Recording Potentiometer
KEY
Cold room thermocouple—located at center on test surface.
Cold room series thermocouple—located 6" from test surface.
Outer box thermocouples—located 2" from outside wall of inner box.
Inner box thermocouples—located 2" from inside wall of inner box.
Inner box thermocouples—located 6" from test surface.
Inner box thermocouple—located at center on test surface.

FIG. 4. DIAGRAM SHOWING ARRANGEMENT OF THERMOCOUPLES IN HOT BOX

value by the hot plate method. Other materials with similar properties may be substituted in the walls and the same conductivities obtained. The general description of the materials as well as their specific properties for each wall in which they were used are given in Table 4.

In so far as possible average commercial materials were selected, but as is well

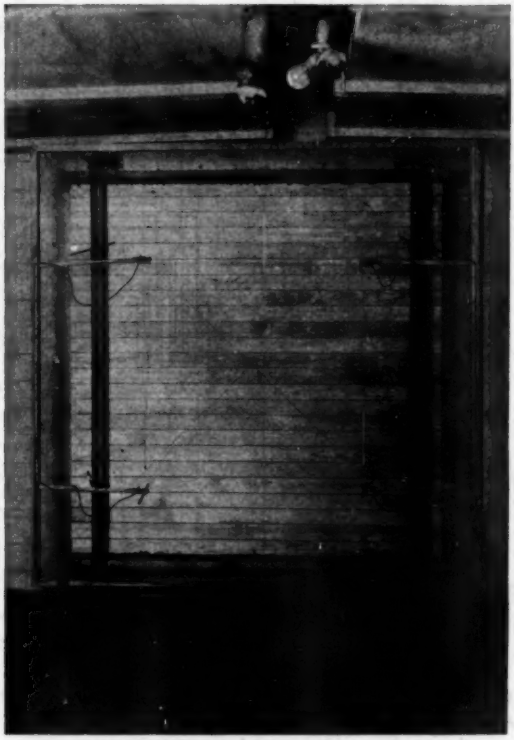


FIG. 5. WALL SECTION IN PLACE FOR TEST

known many of these materials vary in thickness, density and conductivity. Due to this variation and also to the fact that two different walls built up after the same specification will not have identical thermal properties, small differences in the coefficient of transmission U cannot be taken as conclusive in comparing different materials unless such differences are obtained by more than one set of tests.

It will be noted that in the majority of cases only one wall of each kind has been

FIG. 6. INSTRUMENT BOARD FOR HOT BOX TEST APPARATUS

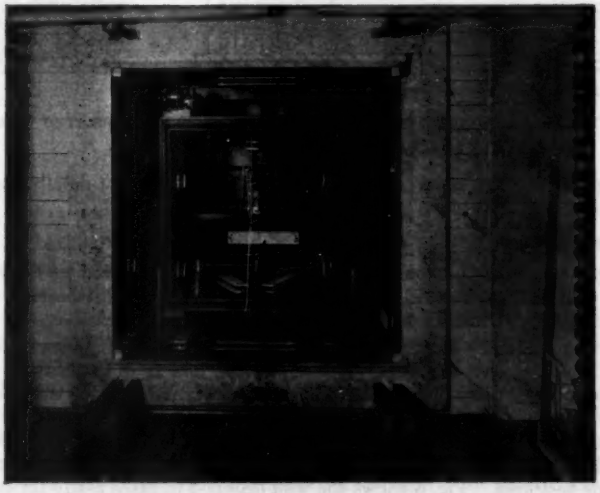


FIG. 7. OPEN END VIEW OF HOT BOX FROM COLD ROOM

tested; some of these will be duplicated as time permits. The variation in conductivity of walls of the same specifications is discussed later in this report.

Description of Test Apparatus

In making these tests both the hot box and hot plate apparatus have been used. Both conform substantially to the standards as given by the code for testing insulating materials by the A.S.H.&V.E. These have been previously described in the JOURNAL, but as several refinements have been made and in previous de-

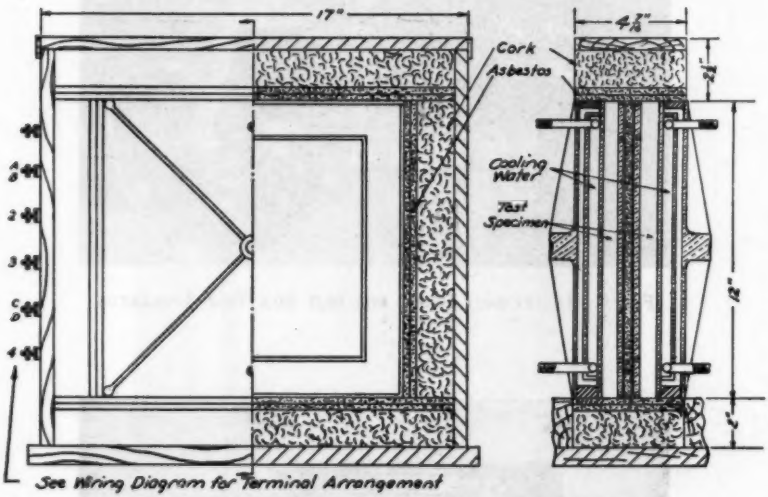


FIG. 8. SECTIONAL VIEWS OF HOT PLATE SHOWING INSULATED GUARD

scriptions there seems to be omissions of some of the important details, the apparatus will be described here.

Hot Box Apparatus

The hot box is of the double box construction built into one of the side walls of the cold storage room. This construction together with heating elements, thermocouples and instruments is shown in Figs. 1 to 7, inclusive.

Referring to Figs. 1 and 2, Fig. 1 is a vertical cross sectional view of the double box with wall section in place. This shows the box as built into the side wall of a cold storage room. Fig. 2 shows a cross sectional view of the cold storage room and open end view of the box with the wall section removed. The wall under test is held in place by locking screws held by two vertical struts which are placed near the outer edges of the test specimen and, therefore do not interfere with the inside test area. Fig. 5 shows the wall clamped in place ready for test. The illustrations show the location of the eight heating elements used in the inner box

and the like number in the outer box. The heating elements are distributed with the greatest number near the bottom. Each element is built up and wound with resistance wire such that four different rates of heating may be obtained from each element.

In order to maintain uniform temperatures throughout the boxes, two 8-in. fans are installed in each box as shown. Those for the inner box are mounted on ball bearings and driven by an external motor at 240 revolutions per minute which is found sufficient to maintain uniform temperature over the test surface and still have practically still air. These fans have been calibrated to determine the frictional heat generated by the bearings and the inside belt connecting the two. All of the current to the inner box is passed through a watt hour meter and the temperatures for both boxes are controlled by thermostats and relays. The location of the thermostats are shown in Figs. 1 and 2.

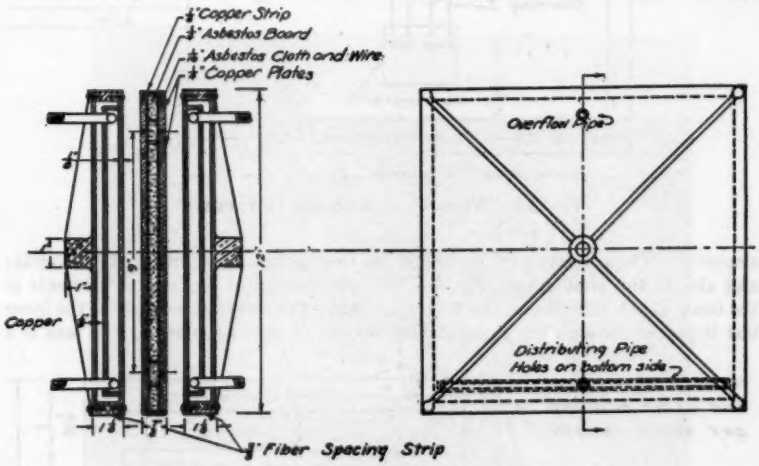


FIG. 9. DETAILS OF HOT PLATE

The air temperatures on the cold side of the test specimen are maintained by a $7^1/_2$ ton ammonia compression refrigerating machine by direct expansion into 1500 ft. of $1^1/_4$-in. pipe in the cold room. It was difficult to get accurate temperature control by use of the expansion valves alone; therefore a small, thermostatically controlled heating unit was installed. The refrigerating machine was set to give temperatures slightly lower than required and the heating unit relied on for the control.

Fig. 3 shows a diagram of the electrical wiring for the heating elements. The heating current is brought to the control switch and fuse block from which point the circuits are taken through relays to the inner and outer box heating

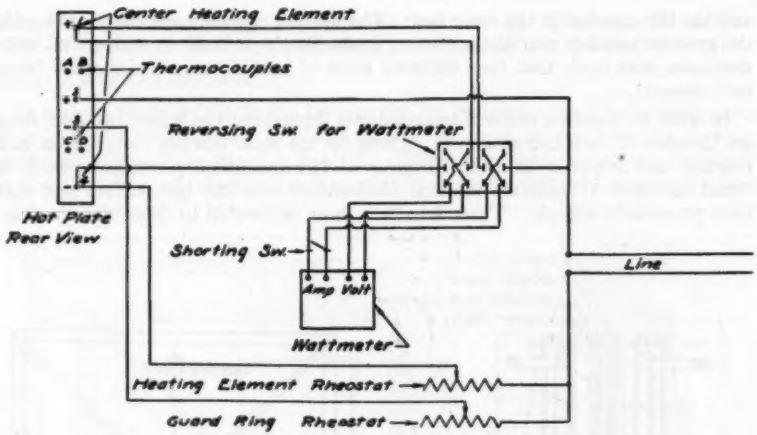


FIG. 10. WIRING DIAGRAM FOR HOT PLATE

elements. These relays are controlled by thermostats as shown in the diagram and also in the photograph, Fig. 6. The distribution of the heating elements in the boxes is not indicated in the diagram. All of the current used to heat the inner box is passed through the meter. The amount of heat supplied by the fans is a

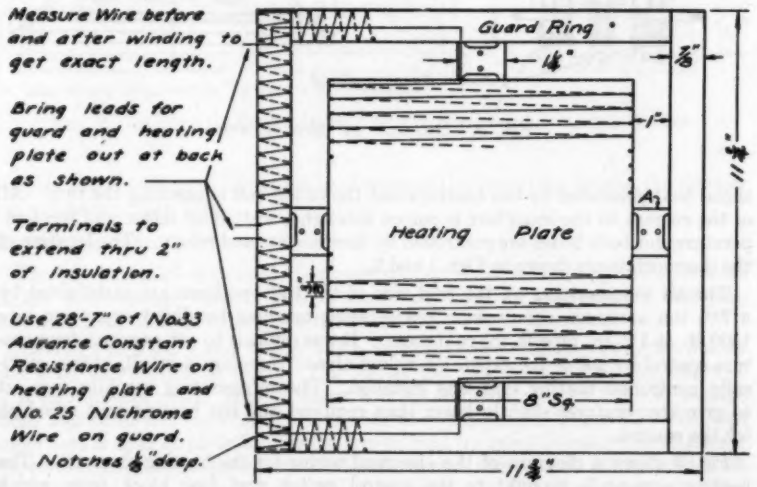

Measure Wire before and after winding to get exact length.
Bring leads for guard and heating plate out at back as shown.
Terminals to extend thru 2" of insulation.
Use 28'-7" of No.33 Advance Constant Resistance Wire on heating plate and No. 25 Nichrome Wire on guard.
Notches 1/8" deep.
Guard Ring
1/4"
7/8"
1"
11 3/4"
Heating Plate
8"Sq.
11 3/4"

FIG. 11. HEATING ELEMENTS FOR HOT PLATE

very small percentage and is taken care of by the correction factor obtained by calibrating the fans.

All temperatures are measured by 24 gage copper constantan thermocouples and a Leeds and Northrup potentiometer. During the period that the test specimen is being brought to constant temperature conditions, a recording potentiometer is used, but after the test is started, all readings are taken with a type *K* potentiometer. A diagram of the thermocouple wiring is shown in Fig. 4. The arrangement of the thermocouples is as follows: one group of five is used to measure the air temperature of the inner box. These are centrally located 2 in. from each inner surface. A second group of five couples each centrally located 2 in. from

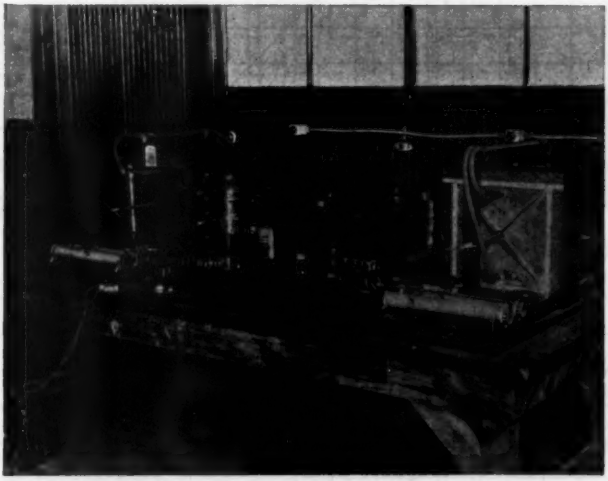
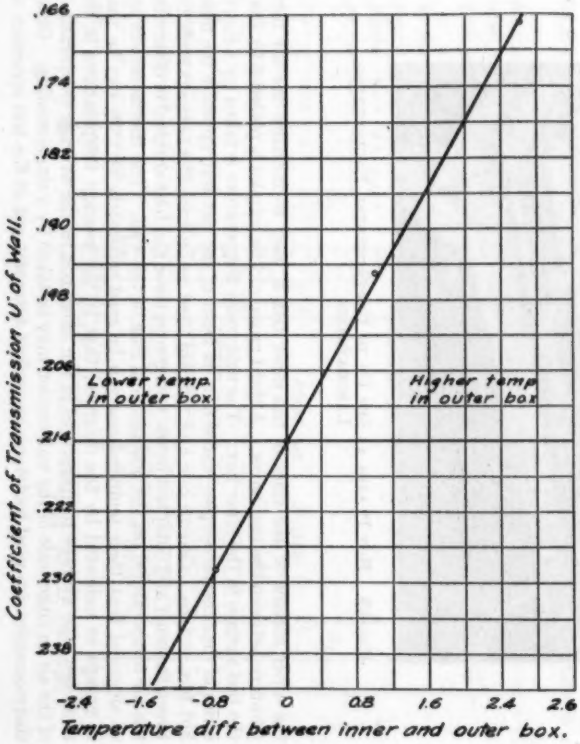


FIG. 12. HOT PLATES AS SET UP IN EXPERIMENTAL ENGINEERING LABORATORIES

the outer surface of the sides of the inner box is used to measure the air temperature between the two boxes. A third group of five couples is placed 6 in. from the test surface in the inner box. The cold room temperature is taken by a fourth series of four thermocouples placed 6 in. in front of the test wall opposite the inner hot box surface. Groups one and two are used to balance the temperatures between the inner and outer test boxes, and groups three and four are used to determine the air temperatures on the hot and cold side of the wall. The thermometers are so arranged that their temperatures can be read separately or they can be read in groups as indicated by the diagram, that is, the average temperatures in the inner box, the average temperatures in the outer box or the average temperatures of the air on either side of the wall section may be taken by a single reading. Other thermocouples are used to determine surface temperatures of the test specimen or



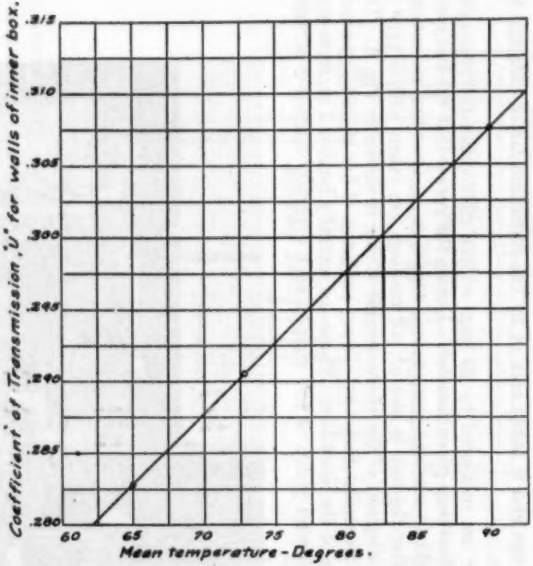


FIG. 13. CALIBRATION CURVE FOR INNER BOX

FIG. 14. COEFFICIENT OF TRANSMISSION *U* FOR WALLS OF INNER BOX ←

any other temperatures required. The various groups of thermocouples are so arranged that they may be read either by the manually operated instruments or by the recorder. The temperatures that are above 32 deg. fahr. are taken by using an ice bath for the cold junction. Those temperatures which are below 32 deg. fahr., as in the cold room, are taken by using hot junctions of known temperature. The thermocouple wires are shown in the photograph of Fig. 7 as distributed throughout the outer and inner boxes. These thermocouples are brought out to the instrument board, Fig. 6, from which any of them may be connected to the

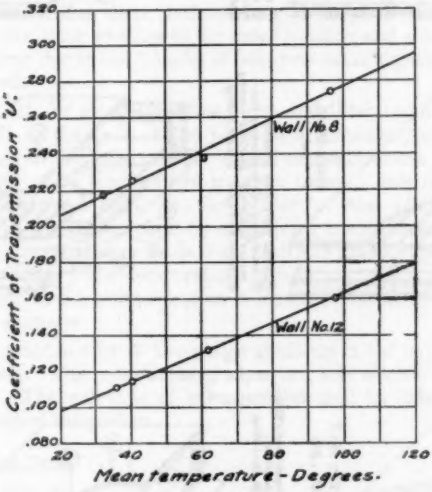
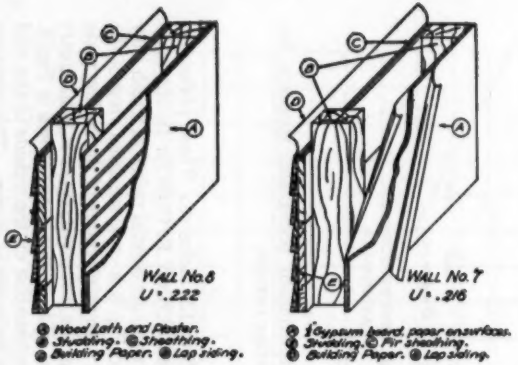


FIG. 15. EFFECT OF MEAN TEMPERATURE ON COEFFICIENT OF HEAT TRANSMISSION *U* FOR WALLS

potentiometer by selective switches. The instrument board also supports the meter relays and switches for the electric heating current.

Hot Plate Apparatus

The hot plates used are shown in Figs. 8 to 12, inclusive. These plates are of the same general design as specified by the A.S.H.&V.E. Code for testing insulating materials but are shown in detail since there are several points in which they have been materially improved. Referring to Fig. 9, a cross-sectional view of the heating and cooling plates is shown at the left with an elevation of the cooling plate at the right. The plates are 12-in. square and the test plate proper is 9-in. square separated from the guard ring by a slot $^{3}/_{32}$ in. wide. This slot is shown in Fig. 8. In order to eliminate the difficulty due to condensation on the outside of the cold plate the cooling chamber is insulated by an air space as shown. This prevents



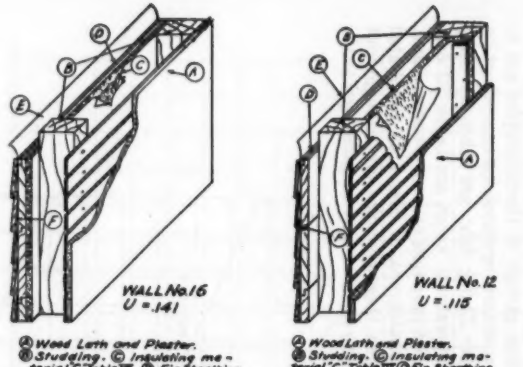
(A) Wood Lath and Plaster. (B) Studding. (C) Sheathing. (D) Building Paper. (E) Lap siding.

(A) ½" Gypsum board, paper on surfaces. (B) Studding. (C) Fir sheathing. (D) Building Paper. (E) Lap siding.

(A) Wood Lath and Plaster. (B) Studding. (C) Insulating board 'B', Table II. (D) Building Paper. (E) Lap siding.

(A) ½" Plaster. (B)(B) Insulating board 'B', Table II. (C) Building Paper. (D) Lap siding (white pine). (E) Fir studding.

FIG. 16. FOUR TYPES OF FRAME WALLS TESTED



(A) Wood Lath and Plaster. (B) Studding. (C) Insulating material 'C', Table II. (D) Fir Sheathing. (E) Building Paper. (F) Lap Siding.

(A) Wood Lath and Plaster. (B) Studding. (C) Insulating material 'C', Table II. (D) Fir Sheathing. (E) Building Paper. (F) Lap Siding.

(A) Wood Lath and Plaster. (B) Studding. (C) Insulating material 'D', Table II. (D) Fir Sheathing. (E) Building Paper. (F) Lap Siding.

(A) Wood Lath and Plaster. (B) Studding. (C) Insulating material 'E', Table II. (D) Fir Sheathing. (E) Building Paper. (F) Lap Siding.

FIG. 17. FOUR FRAME WALL CONSTRUCTIONS TESTED

the cold water from coming in contact with the outer plate. The outer section of the cooling plate is supported on the cooling plate proper by a non-conducting material as shown. The entire plate when built up for test is surrounded by an insulating shield shown in Fig. 8.

The electric winding for the plate and guard ring is shown in Fig. 11. In this winding that portion used for the central or heating elements is entirely separated from the portion used for the guard ring. The copper plate of the central section is entirely separated from the copper plate of the guard ring by a $^{3}/_{32}$-in. slot and the two parts of the plate are held in line by the asbestos bridges or connections *A* of Fig. 11. Thus these connections give the only possible chance for heat to travel from the inner winding to the outer winding and *vice versa*. Therefore the danger of error due to the transfer of heat between the guard ring and heating plate is minimized.

All connections both for electric heating wires and thermocouples are brought through the support at the back of the plate to a common panel from which connections are made to the instruments. These connections are shown diagrammatically in Fig. 10. The temperature is taken on each side of the hot plate by soldering a constantan wire to the center of the plate. The guard ring is balanced with the center plate by connecting a constantan wire between the two and then carrying copper leads from each the guard ring and the center plate to a galvanometer. The temperatures are measured by a potentiometer and the electric input to the central section is measured either by a wattmeter or by a voltmeter and ammeter.

Fig. 12 is a photographic view of two plates as set up in the experimental laboratories for these tests. The potentiometer rheostats and electric instruments are shown in the table. The wall type of galvanometer used for balancing the guard ring is out of the range of the picture.

Discussion of Hot Box Tests

In making tests of the built-up wall sections it was the aim to get complete data covering all materials used. The thickness, density, construction and insulating value of all special insulating materials was carefully determined and in several of the tests thermocouples were placed in the surfaces of materials at each side of air spaces in order to get data as to the value of air spaces and surface constants. In taking surface temperatures the thermocouples were placed flush with the surface and the leads carried back a sufficient distance in contact with the surface to eliminate the effect of lead conduction on the registered temperature. The temperatures of rough irregular surfaces such as stucco were very difficult to obtain accurately. In each case the inner and outer surface temperatures of the walls were taken in order to calculate the surface constant. In the case of plastered or masonry walls the mortar was allowed to cure for at least three weeks before tests were made. All tests were made in as nearly as practical to still air conditions. After a wall was in place for test the proper air temperatures were maintained on both the hot and cold side of the wall until there was a thorough heat balance before any test data were taken. Conditions were then maintained uniform for 8 hours, readings being taken at 15-minute intervals. The constants were checked each hour. The following day a check test was run at least 5 hours in length. In

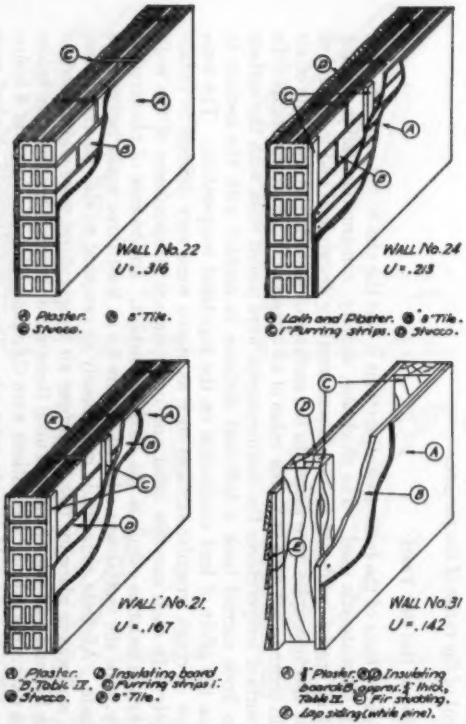

WALL No. 22
U = .316
Ⓐ Plaster. Ⓑ 8" Tile.
Ⓒ Stucco.
WALL No. 24
U = .213
Ⓐ Lath and Plaster. Ⓑ 8" Tile.
Ⓒ 1" Furring strips. Ⓓ Stucco.
WALL No. 21.
U = .167
Ⓐ Plaster. Ⓑ Insulating board Ⓒ, Table II. Ⓒ Furring strips 1".
Ⓓ Stucco. Ⓔ 8" Tile.
WALL No. 31
U = .142
Ⓐ ½" Plaster. Ⓑ Ⓒ Insulating boards Ⓑ, approx. ½" thick, Table II. Ⓒ Fir studding.
Ⓓ Lap siding (white pine).

FIG. 18. STYLES OF TILE CONSTRUCTIONS TESTED

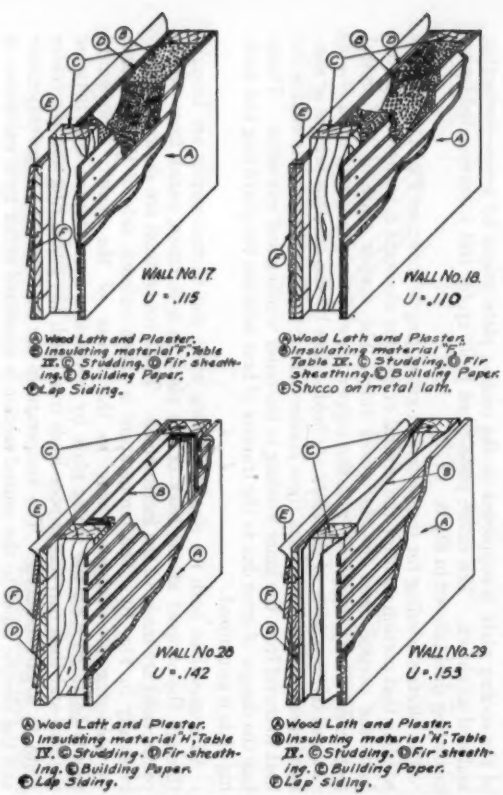

WALL No. 17
U = .115
Ⓐ Wood Lath and Plaster.
Ⓑ Insulating material 'F', Table IX. Ⓒ Studding. Ⓓ Fir sheathing. Ⓔ Building Paper.
Ⓕ Lap Siding.
WALL No. 18.
U = .110
Ⓐ Wood Lath and Plaster.
Ⓑ Insulating material 'F', Table IX. Ⓒ Studding. Ⓓ Fir sheathing. Ⓔ Building Paper.
Ⓕ Stucco on metal lath.
WALL No. 28
U = .142
Ⓐ Wood Lath and Plaster.
Ⓑ Insulating material 'H', Table IX. Ⓒ Studding. Ⓓ Fir sheathing. Ⓔ Building Paper.
Ⓕ Lap Siding.
WALL No. 29
U = .153
Ⓐ Wood Lath and Plaster.
Ⓑ Insulating material 'H', Table IX. Ⓒ Studding. Ⓓ Fir sheathing. Ⓔ Building Paper.
Ⓕ Lap Siding.

FIG. 19. INSULATED FRAME WALLS TESTED

TABLE 1. RESULTS OF TESTS MADE TO DETERMINE COEFFICIENT OF TRANSMISSION *U* FOR INNER BOX

Air Temperatures Fahrenheit

Cold Room Temp.	Inner Hot Box Temp.	Guard Box Temp.	Temp. Guard Box above Hot Box	Mean Temp. Test Sect.	Temp. Drop Test Sect.	Coefficient of Heat Transmission
−8	72.0	72.0	0	32.0	80.0	0.214
−8.1	72.3	73.3	1.0	32.1	80.4	0.1958
−7.0	72.3	74.6	2.6	32.7	79.3	0.1667
−7.6	72.2	71.4	−0.8	32.3	79.8	0.2286

the case of masonry walls it was found necessary to run under constant conditions for a longer period before starting tests, often two days were necessary.

The readings taken throughout the tests were as follows:

Temperatures of inner hot box
Temperatures of outer hot box
Temperature of air 6 inches from inner test surface
Temperature of air 6 inches from outer test surface
Temperature of inner wall surface
Temperature of outer wall surface
Other special surface temperatures when used for air spaces
Electric current supplied to inner box heating elements.

In the majority of tests the air temperatures were maintained at 80 deg. fahr. on the hot side and 0 deg. fahr. on the cold side of the walls, although tests were run at several different mean temperatures on part of the walls in order to get the effect of mean temperature on the coefficient of heat transmission.

Discussion of Hot Plate Tests

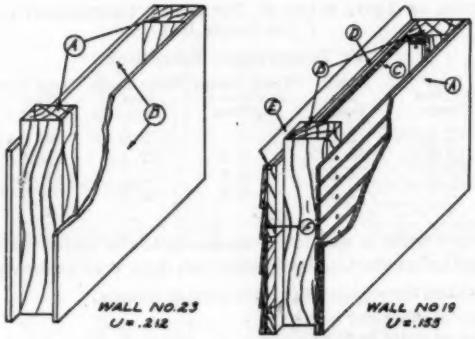
In making the hot plate tests the material was placed between the hot and cold plates in the usual manner, sufficient pressure was used to insure reasonable contact between the surfaces of the plates and the material. The thickness of the material was measured in the plate as tested. The heating current was adjusted to give the proper temperatures and the guard ring balanced. After temperatures had been maintained constant for a sufficient length of time to insure saturated conditions the final readings were taken. The readings taken were:

Temperature of hot plate
Temperature of cold plate

TABLE 2. RESULTS OF TESTS MADE TO DETERMINE THE EFFECT OF MEAN TEMPERATURE ON THE COEFFICIENT OF TRANSMISSION *U* FOR WALL SECTIONS

Wall No.	Test No.	Air Temp. High Side	Air Temp. Low Side	Mean Temp.	Coefficient *U*
8	367	72	−7.6	32.2	0.217
8	373	72.2	−7.4	32.4	0.218
8	374	119.5	72.7	96.1	0.274
8	375	119.5	74.4	96.9	0.274
8	376	119.5	2.4	60.9	0.238
8	400	81.2	−0.35	40.4	0.226
12	405	80.4	0	40.2	0.114
12	406	80.3	−0.1	40.2	0.115
12	421	80.6	−9.1	35.7	0.112
12	423	123.8	−0.3	61.7	0.133
12	424	123.8	71.7	97.7	0.160

XUM

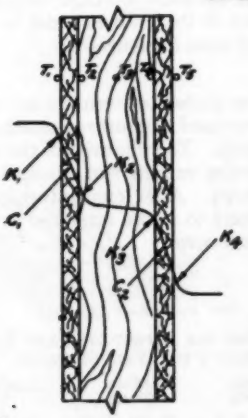


(A) Studding. (B) Insulating Board "G", Table IV.
WALL NO. 23
U=.185
(A) Studding. (B) Insulating Board "B", Table IV.

(A) Wood Lath and Plaster. (B) Studding. (C) Insulating Material "A", Table IV. (D) Fir Sheathing. (E) Building Paper. (F) Lap Siding.

FIG. 20. TWO FRAME WALLS WITH INSULATING MATERIAL

WALL NO. 23.



Results of Tests				
	Cond. Const. Run 1.	M T. Deg.	Cond. Const. Run 2.	M T. Deg.
U	.212	40.3	.213	40.3
C_1	.344	60.3	.368	60.2
C_2	.340	21.7	.330	21.6
K_1	1.75		1.74	
K_2	1.98		1.97	
K_3	2.10		2.06	
K_4	1.64		1.64	
Temperatures				
T_1	70.8		70.6	
T_2	42.8		42.7	
T_3	41.2		41.0	
T_4	33.1		32.7	
T_5	10.4		10.5	

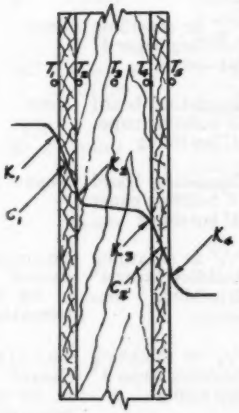
U = Coefficient of transmission Air to Air.
C_1 = Conductivity Constant of Insulating Board "G" Table IV.
C_2 = Conductivity Constant of Insulating Board "G" Table IV.
T = Temperature at Location of Thermocouples.
K_1 = Surface Constant.
K_2 = Surface Constant.
K_3 = Surface Constant.
K_4 = Surface Constant.

FIG. 21. TEMPERATURE DROPS AND CONDUCTIVITY CONSTANTS

Electric energy supplied to heating plate
Thickness of material as tested.

The standard test of insulating materials was made at 60 deg. fahr. mean temperature and on a bone dry basis, other mean temperatures were however used to get mean temperature curves for the materials and the materials were also tested as received, in order to get the effect of moisture on the insulating value and to get the proper constants for checking the hot box results by calculation.

WALL NO. 25.



Results of Tests				
	Cond. Const. Run 1	M. T. Deg.	Cond. Const. Run 2	M. T Deg.
U	.184	40.2	.185	40.3
C_1	.356	61.0	.358	61.0
C_2	.339	23.3	.341	23.2
K_1	1.80		1.82	
K_2	1.92		1.94	
K_3	2.00		2.10	
K_4	1.25		1.28	
Temperatures				
T_1	72.3		72.3	
T_2	49.7		49.6	
T_3	42.0		41.9	
T_4	34.8		34.8	
T_5	11.8		11.7	

U. Coefficient of Transmission Air to Air.
C_1. Conductivity Constant of Insulating Board 'B', Table IV.
C_2. Conductivity Constant of Insulating Board 'B', Table IV.
T. Temperature at location of thermocouples.
K_1. Surface Constant
K_2. Surface Constant
K_3. Surface Constant
K_4. Surface Constant

FIG. 22. TEMPERATURE DROPS AND CONDUCTIVITY CONSTANTS

Calibrations of Apparatus

All thermocouples for both the hot box and hot plate work were read in millivolts and converted into degrees fahrenheit by calibration curves for the various couples. These calibration curves were made by comparison with standard thermometers for the ranges used. The electric instruments in all cases were calibrated by a comparison with standards in the Electrical Engineering Laboratory at the University.

While it was the aim in all wall tests to keep the temperatures uniform in the inner and outer boxes of the hot box test apparatus, this was not always possible and some runs would show a slight variation between these temperatures. In

TABLE 3. DESCRIPTION OF WALLS TESTED

Wall No.	Figure Showing Construction	Type of Wall	Inside Surface	Outside Surface	Special Insulation
7	16	Frame	3/8" gypsum paper on each side	1/4" fir sheathing building paper 4" lap siding	None
7a	16	Frame same as Wall 8	3/8" wood lath 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	None
8	16	Frame	3/8" wood lath 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	None
10	16	Frame	3/8" wood lath 3/8" plaster	Insulating board *B* building paper 4" lap siding	None
11	16	Frame	Insulating board *B* 3/8" plaster	Insulating board *B* building paper 4" lap siding	None
12	17	Frame	3/8" wood lath 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *C* flanged midway in air space between studding
14	17	Frame	3/8" wood lath 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *D* flanged midway in air space between studding
15	17	Frame	3/8" lath and 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *E* flanged midway in air space between studding
16	17	Frame	3/8" lath and 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *C* nailed on studding under sheathing
17	19	Frame	3/8" lath and 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *F* 3 1/2" thick poured between studding
18	19	Frame	3/8" lath and 3/8" plaster	1/4" fir sheathing building paper metal lath and stucco	Insulation *F* 3 1/2" thick poured between studding
19	20	Frame	3/8" lath and 3/8" plaster	1/4" fir sheathing building paper 4" lap siding	Insulation *A* back against sheathing

20	Same as 16 without building paper	Frame	3/8″ lath and 3/8″ plaster	3/4″ fir sheathing 4″ lap siding	None
21	18	8-inch 3-cell tile	1″ furring strips insulation *B* 3/8″ plaster	Stucco on surface of tile	None
22	18	8-inch 3-cell tile	Plaster on surface of tile	Stucco on surface of tile	None
23	20	Frame	Insulating board *G* nailed to studding	Insulating board *G* nailed to studding	None
24	18	8-inch 3-cell tile	1″ furring strip 3/8″ lath and 3/8″ plaster	Stucco on surface of tile	None
25	20	Frame	Insulation *B* nailed on studding	Insulation *B* nailed on studding	None
26		Frame	Insulation *G* and 3/8″ plaster	Insulation *G* building paper 4″ lap siding	None
28	19	Frame	3/8″ lath and 3/8″ plaster	3/4″ fir sheathing building paper 4″ lap siding	2 thicknesses insulation *H* spaced between studs to divide air space into 3 equal parts
29	19	Frame	3/8″ lath and 3/8″ plaster	3/4″ fir sheathing building paper 4″ lap siding	1 thickness insulation *H* nailed to each side of studs bowed in at center 1 1/4″
30	16	Frame same as Wall 11	Insulating board *B* 3/8″ plaster	Insulating board *B* building paper 4″ lap siding	None
31	18	Frame	Insulation *B* actual thickness 0.695 3/8″ plaster	Insulation *B* actual thickness 0.733 4″ siding	None

order to correct for the differences the coefficient of transmission was determined for the walls of the inner box. This was done by taking a wall section and testing it at uniform mean temperatures between the test box and cold room. Tests were made first with the inner and outer box temperatures equal, second with the outer box temperatures slightly below, and third with the outer box temperatures slightly above those of the inner box.

These results are given in Table 1, shown graphically in the curve of Fig. 13.

TABLE 4. DESCRIPTION OF INSULATION USED IN THE DIFFERENT WALLS

Mark Designating Material	Description of Material	Wall in Which It Was Used	Thickness As Used, Inches	Density, Lb. per Cu. Ft.	Conductivity C at 60° M. T. 1 In. Thick Dry Basis
A	Semirigid board	19	0.567	13.3	0.311
B	Wood fiber board	10 Av.	0.514	15.2	0.307
		11 inside	0.525	14.4	0.313
		11 outside	0.531	15.1	0.315
		21 inside	0.535	16.0	0.329
		25 inside	0.534	15.6	0.340
		25 outside	0.519	15.3	0.339
		31	0.706	14.7	0.323
C	Quilted wood fiber between two layers of craft paper	12	0.504	4.8	0.271
		16	0.550	4.5	0.273
D	40 sheets of news paper covered on each side with double waterproofed craft paper	14			No tests made
E	Animal hair lined on one side with tar paper and on other with heavy craft paper	15	0.269	9.7	0.25 at 66° M.T.
F	Porous gypsum material poured into place	17	3.5	11.1	0.436
		18	3.5	11.1	0.436
G	A cereal fiber board	23 inside	0.48	14.3	0.346
		23 outside	0.47	14.1	0.345
		26 inside	0.48	14.4	0.359
		26 outside	0.47	14.8	0.356
H	Paper felt treated on the surfaces with creosote for waterproofing	28 inside	0.119	34.4	0.499
		28 outside	0.119	34.4	0.499
		29 inside	0.117	32	0.470
			0.117	32	0.470

The curve shows clearly the increase or decrease in the coefficient of transmission U due to each degree of temperature difference between the air of the inner and outer boxes. From the curve each degree difference in temperature is shown to change the constant by 0.0182. As shown by Table 1 these tests were made at an average temperature difference of 79.9 deg. fahr. between the air on hot and cold sides of the wall. The total area of the inner box walls is 45 sq. ft. and that of the test wall 9 sq. ft. The transmission constant for the inner box walls is therefore

$$0.0182 \times 79.9 \times \frac{9}{45} = 0.295 \text{ B.t.u. per sq. ft. per degree difference in temperature}$$

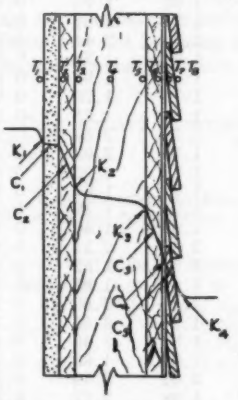
between the air on the two sides of the inner box. This coefficient was obtained for a mean temperature between the air on the two sides of the surface of 72.5. The coefficient for other mean temperatures may be taken directly from the curve of Fig. 14.

Effect of Mean Temperatures on Coefficient of Heat Transmission for Walls

In general, as the mean temperature of any material is increased, the heat transmission constant is also increased. In order to determine the magnitude of this

effect on wall sections two different frame walls were selected; one number 8, without insulation and the other, number 12, with a quilted insulation placed between the studding. These walls were tested at several different mean temperatures ranging from approximately 32 deg. fahr. to 97 deg. fahr. The results of these tests are shown in Table 2 and the curve of Fig. 15. From an examination of these curves, it will be noted that the points lie very closely to a straight line and further, that the slope of the curves for both walls are approximately the same.

WALL NO. 30.



Results of Tests								
	Cond Const Run 1.	M. T. Deg.	Cond Const Run 2	M. T. Deg.	Cond Const Run 3	M. T Deg.	Cond Const Run 4.	M. T. Deg.
U	.154	400	.156	402	.193	474	.194	491
C_1	8.80	727	8.89	725	10.1	119	10.6	119
C_2	.357	624	.362	624	.412	112	.412	112
C_3	.344	322	.347	323	.397	907	.396	922
C_4	2.57	204	2.76	206	3.90	826	4.54	848
C_5	1.24	13.0	1.26	13.4	1.72	783	1.80	811
K_1	1.78		1.80		2.28		2.14	
K_2	1.92		1.97		2.50		2.44	
K_3	2.51		2.49		2.98		2.89	
K_4	1.54		1.52		2.36		2.38	
Temperatures								
T_1	73.2		73.2		119		119	
T_2	71.8		71.8		118		118	
T_3	53.0		53.1		105		106	
T_4	46.6		46.8		101		102	
T_5	41.7		41.8		97.4		98.6	
T_6	22.8		22.9		83.9		85.9	
T_7	18.0		18.4		81.3		83.8	
T_8	8.1		8.5		75.4		78.5	

U=Coefficient of transmission Air to Air.
K_1= Surface Constant.
K_2= Surface Constant.
K_3= Surface Constant.
K_4=Surface Constant.
T Temperature at location of thermocouples.
C_2=Conductivity constant of Insulating Board "B", Table IV.
C_3=Conductivity constant of Insulating Board "B", Table IV.
C_4=Conductivity constant of Building Paper.
C_5=Conductivity constant of Lap Siding (Pine).
C_1=Conductivity constant of Plaster.

FIG. 23. TEMPERATURE DROPS AND CONDUCTIVITY CONSTANTS

The list of walls thus far tested is given in Table 3. This list gives the walls by number, refers to the figure which shows the type of construction and also gives the details of construction. In all cases where wood sheathing was used it was 3/4 in. fir ship lap unless otherwise stated. The lap siding was all 4 in. white pine, 1/2 in. butt. The insulating materials are all designated by letters and described in Table 4.

Table 5 gives the summary of results for all tests.

In order to pick out the results for any one wall refer to Tables 3, 4 and 5.

TABLE 5. SUMMARY OF RESULTS OF TESTS ON WALLS BY THE HOT BOX METHOD

Wall No.	Test No.	Air Temperature °F. High Side	Low Side	Mean Temp.	Inside Surface Constant K_1	Outside Surface Constant K_2	Coefficient of Transmission U
7	401	80.7	−0.05	40.3	1.62	2.08	0.216
	402	80.8	−0.10	40.4	1.62	1.91	0.216
7a	418	80.4	+0.1	40.2	1.75	1.80	0.211
	419	80.5	+0.4	40.4	1.77	1.73	0.212
8	400	81.2	−0.3	40.4	1.72	2.06	0.222
10	403	80.4	−0.2	40.0	1.67	1.91	0.185
	404	80.4	−0.3	40.0	1.67	1.92	0.189
11	409	80.4	0.0	40.2	1.74	2.51	0.153
	410	80.4	0.0	40.2	1.79	2.44	0.152
12	405	80.4	0.0	40.2	1.69	1.74	0.114
	406	80.4	−0.1	40.2	1.65	1.81	0.115
	420	80.5	0.0	40.2	1.74	1.76	0.117
14	393	80.0	0.0	40.0	1.81	1.35	0.132
15	413	80.2	−0.1	40.0	1.75	2.59	0.134
	414	80.2	0.0	40.1	1.78	2.93	0.133
16	415	80.5	0.0	40.2	1.78	1.99	0.141
	416	80.5	0.0	40.2	1.75	1.94	0.141
17	442	80.5	−0.2	40.1	1.75	1.49	0.116
	443	80.6	+0.1	40.3	1.83	1.40	0.115
18	433	80.6	−0.2	40.1	2.02	2.31	0.110
19	425	80.5	−0.1	40.1	1.62	1.82	0.156
	426	80.8	+0.9	40.9	1.64	1.83	0.154
20	437	80.5	0.0	40.2	1.81	3.50	0.225
	438	80.5	−0.1	40.2	1.84	3.40	0.227
21	431	80.5	0.0	40.2	1.84	1.40	0.167
	432	80.6	0.0	40.3	1.83	1.63	0.166
22	445	80.2	0.0	40.1	2.01	2.19	0.318
	446	80.2	0.0	40.1	1.98	2.17	0.314
23	434			40.3	1.75	1.68	0.212
	435			40.3	1.74	1.64	0.213
24	448	80.2	0.0	40.1	1.78	1.65	0.212
	449	80.2	0.0	40.1	1.79	1.85	0.214
25	439			40.2	1.80	1.25	0.184
	440			40.2	1.82	1.28	0.185
26	454	80.1	0.0	40.1	1.65	1.48	0.168
	455	80.2	0.0	40.1	1.65	1.47	0.169
28	456	80.3	0.0	40.1	1.72	1.42	0.141
	457	80.1	0.0	40.1	1.76	1.41	0.142
29	458	80.2	0.0	40.1	1.76	1.60	0.154
	459	80.2	0.0	40.1	1.77	1.58	0.153
30	462	80.1	0.0	40.0	1.78	1.54	0.154
	463	80.1	0.3	40.1	1.80	1.52	0.156
31	460	80.1	0.0	40.0	1.65	1.52	0.142
	461	80.0	0.0	40.0	1.68	1.53	0.143

From Table 3 the description of wall, the figure showing construction and the insulating material used is obtained. From Table 5 the results for the different tests are given.

In all walls where building paper was used over the sheathing it was known as tar felt building paper 32 in. wide, 50 ft. to the roll.

In order to determine the temperature drop, the conductivities of the various materials and the surface constants, three walls, Nos. 23, 25 and 30 were built

up with thermocouples placed on the various surfaces throughout. The location of the thermocouples and the results obtained by tests are shown in Figs. 21, 22 and 23. The thermocouples were placed on the surfaces midway between the studding. In calculating the conductivities and surface constants of the material, the heat units transmitted through the full test section were taken. It is evident that the thermal resistance of the studding would reduce to a certain extent this heat flow and thus affect the surface constants and conductivities. It does, however, represent a practical condition for wall sections.

By comparing the thermal conductivities obtained in these tests with those obtained by the hot plate method for the same material and given in Table 4, the results obtained by the hot plate are found to be slightly less. This may be due partially to the fact that hot plate results were taken on a bone dry basis whereas

TABLE 6. CONDUCTIVITY CONSTANTS *C* FOR MATERIALS BY HOT PLATE AND HOT BOX METHOD

	Material in Wall 23	Material in Wall 25
C by hot plate method	0.35	0.34
C by hot box method	0.364	0.357

TABLE 7. SURFACE CONSTANTS THROUGH WALLS

Wall No.	23	25	30
K_1	1.75	1.81	1.78
K_2	1.92	1.93	1.95
K_3	2.08	2.05	2.51
K_4	1.66	1.26	1.50

the hot box tests were tested as received; and partly to the fact that the material is porous and the transmission of heat by air passage increases the heat flow in the hot box test. The comparison is shown in Table 6.

Surface constants are affected by air motion and it is difficult to measure the exact air motion over the surface of a wall section. The majority of the tests have been made with an air velocity of 40 to 50 ft. per minute over the surface. The outside and inside surface constants as obtained for all tests are shown in Table 5. A summary of those obtained throughout the walls, Nos. 23, 25 and 30 are shown in Table 7.

The inside surface constant K_1 runs very uniform and checks very closely with those obtained throughout other tests. The outside surface constant K_4 corresponds to K_2 of Table 5 and like those of Table 5 the variation is much greater. This variation is due to two causes; *first*, the outside air circulation is more difficult to control and *second*, the outside surfaces of the walls are more irregular and it makes a difference where the temperatures are taken. The constants on the interior of the wall run somewhat higher, 1.93 being a fair average for K_2 and 2.07 for K_3 of walls 23 and 25. In wall 30 this value went to 2.5.

From the tests thus far made 1.75 may be taken as a reasonable value for inner and outer wall surface constants, with an average of 2.0 for the interior constants. These constants depend on many conditions and the values given here are only the preliminary of the study under way.

Variations in Results

By a comparison of the results obtained by duplicate tests on the same wall section it is evident that the apparatus and test methods are reliable and that results are easily duplicated on the same test section. If, however, two different walls are built up after the same specification there is a variation due to materials. This is apparent by comparing walls 7*A* and 8. These walls were built at different times but from materials of similar specifications. When tested wall 7*A* gave a coefficient $U = 0.212$ while 8 gave a coefficient $U = 0.222$. From an examination of the walls the only apparent difference between the two walls was in the thickness and sap in the sheathing. In another case in which white pine was substituted for fir sheathing a still greater reduction was noted. On the other hand the two walls, Nos. 11 and 30 were built up of the same stock of insulating board used both as a plaster base on the inside and as sheathing on the outside. These walls tested 0.152 and 0.155, respectively. If materials can be exactly duplicated then the test results may be duplicated, but in many cases this will be impossible. With many of the quilted materials, there is a spread or increase in thickness when it is flanged between the studding. This increase is not uniform and may make a wide variation in the constant obtained. For this reason definite comparisons of the value of different insulating materials should not be made from the tests on one wall of each kind. Many of the wall constructions have been duplicated and are in the process of testing; others will be duplicated and reported with new types of construction at a later date.

Effect of Moisture in Walls

With those walls which contained more wet material in their construction a longer period was necessary for drying out before testing. For instance with wall No. 17, this was dried 4 weeks and then tested, giving a transmission coefficient U of 0.123. It was then allowed to dry for 4 weeks longer when a test gave $U = 0.115$. It is possible that if dried for another month it might have given a still lower constant. Likewise wall No. 18 after drying for 6 weeks gave a coefficient of 0.125. This same wall after drying 10 weeks longer gave a coefficient of 0.110. This shows the necessity of thoroughly drying the walls before test.

The authors of this paper wish to acknowledge the cooperation of F. C. Houghten, director of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS' Research Laboratory and also the work done by C. C. Carlson in obtaining the hot plate constants for the materials used.

DISCUSSION

P. NICHOLLS (WRITTEN): Professor Rowley's paper is of particular interest because the guarded box method he is using is included in the code for testing insulating materials which has been tentatively adopted by the Society. There can be no question but that the method is sound and that it should give accurate results as far as "accuracy" is limited to the construction as tested and the conditions surrounding the testing. This limitation is particularly necessary with built up sections where workmanship and age will affect the construction and the air circulation in the interior.

Such testing work will always be investigative rather than standardized testing, and the method and set-up used will be varied or attempts at improvement made in the same manner as Professor Rowley has changed the construction of his hot plate from the design set up by the Bureau of Standards.

There is no reason why other investigators could not duplicate Professor Rowley's apparatus and obtain approximately the same results, although surface coefficients are liable to differ due to changes in the air circulation. It is questionable, however, whether it is necessary to make the boxes as deep, and half that used should be satisfactory. It would also be preferable to distribute the heating elements, there is no reason why the wires should not stretch across the box, thus avoiding localized heating.

Professor Rowley obtains equilibrium between the inner and outer box by thermocouples measuring the air temperatures. Would it not give more assured accuracy, and also greater ease of manipulation, to use systems of differential couples on the 5 sides of the inner box? These systems could be connected in multiple so that only one reading would be necessary to maintain balance during the test, while each side could be balanced in the preliminary tests when the best heat distribution to the heating wires was being found.

All but three of the wall sections tested had the same inside finish, and it would, therefore, be expected that all the inside surface coefficients would be the same, or would increase slightly with the conductance of the section; the differences found were probably due to the air circulation or to the location or method of attaching the thermocouple.

This also is largely true for the outer surface, with the exception of wall 20, but it is hardly correct to call the 3.50 a surface coefficient as the high value was evidently caused by the air circulating through the slats because there was no paper lining behind them, and is an infiltration effect.

Because inner surface coefficients need not be measured as their values in service can be assigned from known data, a hot plate method arranged to give a one-direction flow could be used. This principle was used by the speaker and is described on p. 300 of the 1924 TRANSACTIONS. It gives uniform heat distribution and has possibilities of a higher order of accuracy in the heat input measurement. The box method, however, is superior in that it should be possible, with proper precautions, to include the effect of heat loss from infiltration caused by wind pressure. In making comparisons of constructions, particularly when they include special insulations, it would be well to determine whether their transmittances are affected by wind pressure, and it is hardly fair to compare them on a still air basis. It is suggested that a wind test should be made as a standard test in addition to the one with still air.

The University of Minnesota is doing a good work and it is to be hoped that it will be continued and not interrupted as has so often occurred due to institutions changing personnel. When completed it will fill a big gap. The most complete and best work to date on building construction heat transmission is that done by Kreuger and Eriksson in Sweden. It was carried out by the Academy of Engineering Science, the money being supplied by the government during the years 1920 to 1924. Over 50 wall sections were tested and a number of special studies made on surface coefficients, air spaces and other factors. The results were con-

nected with the climatic conditions in different parts of the country and are well presented for practical application.

The method employed by Professor Kreuger was the same in principle as that being used by Professor Rowley, but instead of having a special outer box he balanced the inner box against the room temperature.

Many of the wall sections tested are not used in America, but in spite of that it would be worth while for the Society to sponsor the translation and publication of the two bulletins, numbers 7 and 24, issued by the Academy.

M. S. VAN DUSEN[1] (WRITTEN): Professor Rowley and his associates are to be congratulated on their excellent work on heat transfer through building materials and constructions, and especially in their efforts toward the correlation of results obtained on homogeneous materials in the hot plate and those obtained in completed walls by means of the box method. The ultimate goal in heat transfer research of this kind is obviously to show, if possible, that calculations of the insulating properties of built up walls using data on single materials and air spaces can be relied upon for practical purposes.

A few points in this paper, however, seem to require critical comment. The effect of mean temperature on the heat transfer coefficient was determined for walls No. 8 and 12, both showing a considerable increase with mean temperature. The slopes of the two curves are practically the same, but the percentage slope, in which we are really interested, is about 0.8 per cent per deg. fahr. for wall No. 12, which is about twice as great as that of wall No. 8. If all heat through wall No. 12 took place by radiation only, we should expect an increase of approximately 0.8 per cent per deg. fahr., but this is far from the case with this wall. The increase in convection and conduction with mean temperature is much less than 0.8 per cent per deg. fahr., according to practically all available data, and it would therefore appear that the slope of the curve for wall No. 12 is much too great. The percentage slope of the curve of wall No. 8 appears to be reasonable enough, but according to fairly well established principles, its percentage slope should be greater than that of wall No. 12, since a greater proportion of heat transfer by radiation occurs in wall No. 12. Walls containing no air spaces across which heat transfer by radiation could take place should have a temperature coefficient only a fraction of 0.8 per cent per deg. fahr., according to available data on the thermal conductivity of various building materials.

The interpretation of heat transfer across an air space by means of two so-called interior coefficients seems rather illogical. An air space is a definite thing in spite of the fact that the heat transfer across such a space occurs by three general methods and is affected by temperature difference, mean temperature, character of surface, height, width and possibly other factors. It would appear logical to consider an air space as a unit, and at least not divide up the heat transfer across such a space into two completely fictitious "interior coefficients." The combination of two such coefficients has a physical significance, but neither one separately has the slightest, since the radiation which accounts for more than one half of the total heat transfer across an ordinary air space is independent of any intermediate air temperature between the bounding surfaces of the air space.

[1] U. S. Bureau of Standards. Member Committee on Heat Transmission, National Research Council.

It appears at first sight that too much importance is attached to the so-called inner and outer wall surface constants as measured in the apparatus. In spite of the fact that the inside air is only moderately stirred to promote temperature uniformity, nevertheless the conditions prevailing inside the box are in all probability considerably different than those on the inside of a room of average height, and the surface constants are therefore considerably different. Likewise the outer wall surface constant, as determined, bears little relation to conditions on the outside of an actual building. The conductance of the wall specimen from surface to surface would appear to be the important quantity determined in this series of tests. It seems impracticable to attempt to simulate actual surface conditions in any reasonable box method of test. In applying results on the conductance of walls to actual practice it is necessary to add a certain thermal resistance due to the outside and inside surfaces in contact with air. Such resistances are probably as well known now for vertical surfaces as they ever can be, applied to the calculation of heat losses from actual buildings. Tests for the express purpose of determining this resistance under still air conditions have been made. The sum of the inside and outside surface resistances of a wall is on the average equal to 1 deg. fahr. per unit heat flow expressed in B.t.u. per hr. per sq. ft. This figure assumes that the outside surface resistance is on the average roughly on half of the inside surface resistance. It is subject to large variation depending on conditions which can only be very roughly defined in practice, but its use is probably as accurate as we can hope to be for a long time to come.

I do not wish to be misconstrued as decrying the efforts of those engaged in the determination of surface constants, but the results of such determinations should be set in their proper place, and as additions to scientific knowledge such test conditions as air speed, etc., should be clearly defined; otherwise the results are of little value scientifically.

This leads us to the question of whether or not it might be more logical to test walls, as well as homogeneous materials, by the plate method. This has been done to some extent in Europe. To my mind the choice of the two methods depends entirely on the ease and accuracy with which the conductance of walls can be determined. If the box method is simpler and more accurate, it is undoubtedly the best method, but its advantage does not lie in the fact that with it certain particular surface constants can be determined.

F. G. HECHLER[1] (WRITTEN): These two papers are important contributions to the literature on the heat transmission of wall sections and go a long way in bridging some of the gaps between laboratory data and service results.

The data are presented in an admirable and convenient form for the average reader, but for those who wish to make a further analysis of the results fuller test data would be very desirable. The care taken in adequately describing the materials used is gratifying; the one exception, noted in both papers, seems to be plaster. The conductivity of cement plaster is usually taken as 8.0 B.t.u. and that of gypsum plaster as 2.32 B.t.u. Even though plaster has little effect on the total thermal resistance of the average wall it would be well to specify the kind used. Professor Rowley apparently used cement plaster in his test. On the other

[1] Professor of Engineering Research, Pennsylvania State College. Member Committee on Heat Transmission, National Research Council.

hand Mr. Houghten in Table 7 gives a value for wood lath and plaster "as used" which refers to gypsum plaster.

There has been a great deal of discussion of the methods of measuring heat transfer, and the hot box method has been severely criticized. The comparative conductivity values given by Rowley in Table 6 are concrete evidence that in the hands of skilled experimenters the hot plate and the hot box methods give results that are consistent and in quite good agreement. It is usually recognized by all who have used the box method that the location of the fans as well as the air velocity and the angle of impingement of the air stream have considerable effect on the results obtained. It is interesting to note that Professor Rowley does not direct the air stream toward the test wall; so far as the writer recalls, this point has not been brought out in previous descriptions of the apparatus. It still remains to be seen how well results obtained by this method in different laboratories and by different experimenters agree. A typical test log would be interesting to show how nearly the ideal condition of constant and uniform temperatures throughout the test box is realized. This has always been difficult to get, and as Professor Barker has so aptly stated, must be experienced to be appreciated. The writer has yet to see authentic hot box test data where the temperatures within the box were all the same and remained so during the run.

One of the most valuable results brought out by Professor Rowley's tests is that for a wall with an air space the surface coefficients within the space have a mean value of about 2.0. This means that the resistance of such an air space is 1 and not 1.49 which is the value now generally accepted in this country. There is considerable evidence bearing out the validity of this result, the most recent being on the work radiation by Griffiths in England and Heilman at Mellon Institute, and there are reasons for believing that our constants need revision in this respect. It is to be regretted that the present series of heat meter tests give no data regarding the value of air spaces as found in walls.

Rowley suggests that 1.75 is a far value for both inner and outer external surface coefficients; this is equivalent to a total combined surface resistance of 1.14 which is about 14 per cent higher than the conventional value of 1. Here again even a considerable change in the value of the surface coefficients will have little effect on the thermal resistance of a well insulated wall. Under service conditions the surface coefficients show wide variations, and are influenced by many factors beyond control. One of the most potent influences is the kind of wall exposure, for example, if the sun shines on a wall its surface temperature becomes much higher than that of the ambient air and the surface coefficient consequently very low, sometimes even lower than the inside coefficient. Normally, however, we are interested in knowing the value of the coefficients under the most unfavorable conditions such as for a northern exposure, during the night, or for stormy weather. It is certainly convenient to take the sum of the two surface resistances as unity and evidence seems to prove this to be true also for air spaces.

The 8 in. concrete slabs tested at the Research Laboratory gave conductivities ranging from 13.3 to 16.4. It will be recognized that these values are much higher than those usually used. The results, however, agree quite well with data obtained at Pennsylvania State College on some concrete slabs six to eight years old. The slabs appeared to be dry but as they had been stored for several years in a damp,

cold room they probably held considerable moisture which may account for the high conductivity. Undoubtedly, in service, concrete walls are frequently quite damp and have a high conductivity. The same applies to many brick walls and probably the conductivity value of 4 usually used for brick is generally too low. Of course there are may kinds of brick and we really need some definite method of identification, but for the broad generic classification of just "brick," a conductivity of 5 would probably be more nearly correct. We already specify 5 for wet brick; but what is meant by wet brick, and who will admit that this wall is going to be wet? In a paper presented at a joint meeting of the *A.S.M.E.* and *A.S.R.E.* in December, 1927, the writer reported tests showing that even a small amount of moisture may greatly increase heat transmission in a brick wall. The capillarity of the average brick wall is well known and too much reliance should not be placed on such a wall being or remaining dry.

The agreement between the measured and the computed conductances in Table 6 of Houghten and Zobel's paper is noteworthy and is further evidence that the thermal resistance of a wall can be accurately calculated from reliable values for conductivities of the material used. This result is of the greatest value and amply justifies the time and effort devoted to the problem.

C. K. SWIFT (WRITTEN): It is particularly gratifying to note the attention given by the authors to a more exact evaluation of the surface coefficients. The available data on these constants are vague and in many cases inaccurate, and are unquestionably responsible in a large measure for discrepancies between calculated and actual transmission coefficients.

Of equal importance from my point of view are the results on the temperature coefficients of transmission. The results as given by the curves in Fig. 15 are rather surprising. In the case of Wall No. 13 an extrapolation of the curve would indicate a zero value for U at approximately 100 deg. below zero. While the point is one of purely academic interest it is difficult to conceive of a wall becoming a perfect insulator at a mean temperature 360 deg. fahr. above absolute zero.

In the determination of the temperature coefficient of conductivity, I have obtained similar results on several occasions. Conductivity values plotted with respect to mean temperatures fell almost exactly on a straight line, but the slope was such that zero conductivity was indicated at temperature values well above the absolute zero.

It is probable that the apparent anomaly can be explained on the basis of a change in the slope of the temperature coefficient curve at a point below the lowest observed values, but the reason for such a variation is difficult to understand.

THORNTON LEWIS: I think this work that has been going on is most excellent. I would like to add my personal vote of thanks for such a valuable contribution to the Society.

I really got up to ask this question: Here we are finding by actual test the B.t.u. constants for certain surfaces. In the paper that was presented yesterday from the Research Laboratory we have other surfaces that are being tested, and I understood Mr. Houghten to make the statement that certain materials or constructions that were tested showed different values from those that were calculated, and are now in THE GUIDE.

The question I want to ask is this: What practical method have we, or what practical method are we going to set up for bringing into harmony those two sets of values? I think that is important. There are a number of bodies, trade associations, etc., that are looking to this Society to guide them on this engineering information relating to heat transfer, in addition to the many contractors and engineers and private firms who are expecting this data from this Society.

Now, we ought to definitely set up some method for bringing those two things together and see that the constants we publish in THE GUIDE which are generally being used are revised, and so state at the time they are revised that they are considered up-to-date information which has been passed upon by our Research Laboratory or the Research Committee.

I ask that, Mr. President, in the form of a question.

F. C. HOUGHTEN: As pointed out by Mr. Lewis the study at the Laboratory shows heat transmission coefficients somewhat different in a few cases from those used in THE GUIDE. The only two really important cases are concrete and hollow tile constructions. I believe that all other variations are no greater than one would expect from tests on different walls of like construction and materials built by different workmen.

The question of incorporating changes in heat transmission values in THE GUIDE, based upon these differences, rests with The Guide Publication Committee. Whether or not changes should be made in THE GUIDE depends on whether or not the hollow tile in the walls tested is typical of that used throughout the country. In so far as we have been able to determine, it is typical. It is possible, however, that the heat loss through hollow tile walls depends upon the particular tile used or even on the clay from which they are made, and it may develop that it is desirable to classify hollow tile.

As pointed out in the paper, the concrete wall tested was not poured very long and its conductivity is decreasing with time. It remains to be seen whether or not this decrease in the coefficient continues until it reaches the value in THE GUIDE or whether we should accept a higher value for concrete. Again it is quite probable that the conductivity of concrete depends upon the proportion of cement, sand and gravel in the mix, and even upon the stone particles in the sand and gravel. It is quite probable that sand and gravel, whose particles are largely limestone, will give a concrete with a different heat transmission coefficient from concrete in which the sand and gravel particles are largely granite.

E. C. EVANS: I would like to ask Professor Rowley if there has been any attempt to stipulate or find out the amount of cement or plaster that is used in a tile wall. I think that is where this constant varies as represented by the hot box, and I don't believe we will ever find that we are able to use the formula and the fixed values that we get because we are up against the workman who in laying up the wall, slaps a little mud on the corners. I think considerable attention ought to be paid to this until, as the years go by, we will get what we call a tile wall.

W. H. CARRIER: There is one point in this paper that I would like to inquire about. I presume Professor Rowley has taken care of this. I didn't have an opportunity to read the paper very carefully, so that it may all be there, and I have not noticed it. So, if it is, pardon my question.

That is a question in reference to the protection of radiation from the heating element. Even if the heating element is surrounded by a casing, that casing has considerably higher temperature than the surrounding air, and the radiation factor is considerable. I think that has probably been one of the chief difficulties in the past in standardizing a hot box method. I think probably there has been insufficient protection for the heating element which would have the effect of producing higher surface temperatures than indicated by the surrounding air, also it might have the effect, if not guarded, of affecting the thermometer reading. I assume that in this case it has been taken care of, only I should like to have had the mention of it made a little more prominent.

I was greatly surprised to see results reported by the Smithsonian Institution with an instrument for measuring radiation in which under certain conditions, plain surface, cloth-covered surface or blackened surface, the radiation at normal blood temperatures about 100 deg., room 70 deg., the radiation effect is said to be 60 per cent of the total heat, and only 40 per cent by convection.

Prof. Rowley may know more about that than I do; he has been making investigations along the same line. When you have such a tremendous proportion of radiation to convection, you can easily see the opportunity for an error by radiation effects that are away beyond what we have ordinarily considered. I had no idea they were of so great a proportion. Not only must the heating element be encased, but as the casing is warm, and there will still be considerable radiation, you must protect it by a further insulating guard with an air space in between, a real insulator, so the outside of the insulation is practically the temperature of the circulating air. Even that must be protected against the sides of the box because you will get the radiation against the further sides of the box; that box will be hot and radiate back.

A very good illustration of radiation effect is in an electric toaster or broiler where the heat is radiated right down through the cold air, and you can broil or toast with air practically at the freezing point, which shows that radiation effect is very, very important. Now this same effect exists, although not to as great an extent, at a temperature difference as low as 30 deg. so that the percentage of radiation is still a large proportion of the total heat emitted. So it is very important that great care be taken to guard against radiation effect in the box which will give different results every time the amount of radiation is changed or a different type of radiator is used. It is obviously requisite for standardization that, regardless of what type of heating element is used or its arrangement the method must be such that there must be no effect in the overall results obtained. This means that there must be *no* radiation effect from the heating element either to the box or to the thermometric element, and that the air in the box must be heated by convection only, and the walls be heated only by convection from the air. Another point which needs to be taken into account is that the heated air must be so distributed that there will be as nearly as possible uniform air temperatures in all parts of the box, and this must be accomplished with the minimum of air disturbance. The velocity of air movement near the surfaces should be taken into account and preferably independently measured by a hot wire anemometer.

The other method that might be considered is to distribute the heat almost entirely by radiation with the radiating elements so distributed that the surface

temperatures would be uniform. In this case, only the surface temperatures would be measured and corrections would have to be made for the difference between room temperatures and the surface temperature of the material in the practical constant of transmission of the structure. Possibly this would be the simplest way.

I didn't want to make that as a criticism, because that I presume has been taken care of, but I think it ought to be emphasized.

The point has been brought up by Mr. Lewis about the method of getting our data to the rest of the world in general. We are a small society here. I mean we are small compared perhaps with the electrical and mechanical engineers. We are a large society considered from the standpoint of what we were a few years ago, and from the standpoint of similar organizations in other countries. I don't know the number of engineers in this country, but I assume that there are at least twenty or fifty times, possibly a hundred times, the number in our organization. That is, those who belong to other societies and those who do not. A large percentage of those, possibly half or a little less, are interested in heat transfer in some form or other—insulation or promotion of heat transfer. The pioneer work that is being done by this Society is of vital importance to all such engineers. I think there may be a little tendency in any society to be a little narrow in their view, and think only of their own interests, their own point of view, their own problems, and forget that the same problems are to a greater or a lesser degree the problems of half of the rest of the engineering profession.

We want to get away from that if we can and consider ourselves not as heating, ventilating engineers, but as thermal engineers. We are a part of a large group of engineers, a great number of which are outside your own body, and the work this Society is doing along this line should be made available to these men. That will bring the Society into prominence of having done a great work for all of these engineers.

I have spoken to you before about what we are attempting to do in the National Research Council through the Committee on Heat Transmission. That was started really by some of the refrigerating engineers wanting to get something done. They are not as fortunate as you in having a research laboratory, and they wanted to tie up all of these various investigations that are going on so that they could be made generally available. Now, fortunately for you, I think about half of the membership that is present on that committee belong to this Society, and through that committee we are able to work with the electrical engineers, the ceramic engineers on high temperature work, which work in a similar manner to your Society along their own line. *The American Society of Mechanical Engineers* and the *American Society of Refrigerating Engineers* must have exactly the same problems in insulation, heat transfer, as you have, and I want to see this Society carry on this work, and through this coordinating organization, if possible, that they may have the honor and the prestige of having done some real work along this line. I am very glad to see that we are going on in this way.

H. S. ASHENHURST: This work that Professor Rowley is doing is, I think, a step in the right direction, but I think we should, as a Society, try to get before the public just exactly what insulation means. For example, when we test walls, we generally test them under what we call laboratory conditions. That is, we

test them as if the building was constructed under the best possible circumstances, and when we test the side wall, generally the top is sealed.

What I think we should do in going into this work is to give tests to show what will happen under certain construction conditions. That is, if the wall is sealed at the top, that should be noted. In ordinary building very little attention is paid to construction, and the test should be made with the walls in the ordinary way; that is, open at the top, to see what the result would be. Then I think it is important in making a test that the question of air conditions should be considered because we very rarely have in this latitude any still air. What the public wants to find out is just exactly what will happen in the insulated building, under all air conditions.

So I think the thing for us to try to get across to the public is just how must I build my house, what thickness of insulation shall I put in and how shall I fix it in the walls in order to get a certain reduction in heat losses over the house built in the ordinary way.

Now, there are several things that have been done recently along that line. The American Gas Association in its insulation committee has been trying to show what various thicknesses of insulation have meant in buildings. The Better Business Bureau has been trying to get the insulation manufacturers to tell the truth about insulation in their advertisements, and they have tried to have a code adopted so that the manufacturer of the state, in order to get a certain heating saving, will have to apply his insulation in a certain way and put in a certain thickness. What I would like to have us do in the Society is to be able to tell the public—the public knows nothing about B.t.u.'s and engineering figures—how to build a house to get the best results and to say to the public, if you put a certain thickness, a certain kind of insulating material in your walls, put it in in a certain way, paying special attention to methods of application you can then be pretty well assured of a certain definite saving, whether it is five, ten, twenty, thirty or forty per cent.

I would like to see tests carried out and information gotten to the public so that we can say to the public, if you build your building in a certain way, and insulate it in a certain way, you can get probably about this much saving.

Of course, we know a lot of things enter into it that we can't tell exactly, but when you once get the truth about insulation before the public and try to get things out in a practical way so the layman knows exactly what to do, I think we will accomplish a great deal.

C. G. SEGELER: Hearing Mr. Ashenhurst speak tempted me to bring up this little sheet which I managed to total off before I left for the convention. This is a computation of some two hundred gas-heated houses located in various parts of the country, Michigan, New York, Webster Grove, Dayton, Ohio, etc., and is only a small part of the total number which I propose to tabulate before I am through. In each house, the heat transmission coefficients of THE GUIDE were used to calculate the heat loss through glass walls, roofs, doors, and also to calculate the heat loss by infiltration, using window crack.

The results in percentage of heat loss through the various parts of the house are as follows: heat loss through walls, 27% of the total; through roofs, 16.2%; through glass, 25.8%; through doors, 4.3%; by infiltration, 24.6%.

This has a very important bearing on the insulation question, and of course, in response to Mr. Ashenhurst, insulation is of the greatest importance to the gas industry where the fuel prices are higher and where the proportionate savings should be greater. The proportionate losses that I have given will give some indication of where the greatest value received per dollar spent for insulation might be recovered. Offhand, our indications at present are that tightening of window frames and use of weather-stripping are the easiest possibility for savings. Of course, the walls and roofs must not be forgotten, either.

PROFESSOR ROWLEY: Some of these discussions need no reply. They are more or less constructive criticism of the nature we need in this class of work.

Mr. Evans brought up a point of the amount of mortar between the joints as affecting the conductivity of a tile wall. While the amount of mortar does affect infiltration, I believe our real difficulty in tile walls has been lack of knowledge concerning the value of an air space. I think perhaps we have over-rated air spaces and there certainly are some things which we do not know about internal surface constants. In this work we are trying to separate infiltration from conductivity losses.

Mr. Carrier's point on radiation is well taken. Radiation losses are an important factor and we are apt to lose a lot of heat for which we cannot account. Our radiation losses are taken care of primarily by using low temperature heating elements. When all of the heat is turned on the elements, one can still hold his hand on them without any discomfort. The maximum temperature of the elements is maintained below 200° F. and the average working temperature is much below this point, thus reducing the possibility of radiation losses. Formerly, we used electric light bulbs for heating elements in the inner box. In order to prevent radiation in this case, we shielded the lights but did not find any difference in the final results.

Mr. Nicholls brings up the question of the surface constant in wall No. 20. I ought to have stated that this wall was run at a high air velocity thus giving a high surface constant.

Mr. Ashenhurst brings up the point of testing walls as they are actually built up without any stops at the top and bottom. One can readily see what would happen with the average wall if it were left open at top and bottom. It would be substantially a chimney and the transmission would be only that of the inner surface. As a matter of getting the results over to the public in a practical way, this is the ultimate aim of the research work, but we must know what we are getting to the public and be sure that it is based on facts.

No. 812

A STUDY OF DUST DETERMINATORS

By FRANK B. ROWLEY,[1] (*Member*) AND JOHN BEAL,[2] (*Non-Member*)

MINNEAPOLIS, MINN.

IN order to write an intelligent code covering the testing of air filters the air filter code committee felt that it was essential to learn more about the characteristics of the different dust determinators. For that reason part of the cooperative research work between the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the University of Minnesota was conducted along this line.

The purpose of the present experiments was to study the various methods which have been proposed for determining dust in the air, and if possible, to select those best adapted to the practical development of a code. This work has not been finished although the apparatus has been built up and a considerable amount of experimental work has been done on the A-A Determinator.

One of the first problems was to devise a method of mixing dust with air which would give a reasonable degree of uniformity in the mixture. In order to do this an apparatus was built up as shown in Figs. 1 and 2. Fig. 1 is a plan view showing the general arrangement of the apparatus. The dust chamber *B*, 4 ft. sq. and 8 ft. long, serves as a space for thoroughly mixing the dust with the air by a mixing device shown in Fig. 2. The mixture from this chamber is drawn through a reducing section to the $12^1/_2$-in. diameter inlet of a number 2 Sirocco fan directly connected to a $^1/_2$-hp. d. c. motor, the normal speed of the motor being 850 r.p.m. This fan serves to further mix the dust and air and delivers it to a 20-in. square duct 21 ft. 8 in. long. Four feet eight inches from the end of this duct an air filter is placed. The details of the method of placing the air filter in the duct are shown in the vertical section *AA*. Air is prevented from leaking past the filter by placing an ordinary automobile tube between the outside of the filter and the casing and inflating the tube. There is a $4^1/_2$-in. diameter hole with a cover plate provided on each side of the filter for sampling the air and also a hole one inch in diameter on each side for determining the pressure drop across the filter. Five feet in front of the filter face a brass strip is placed across one side of the rectangular duct and

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The results of cooperative research between the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and the University of Minnesota.

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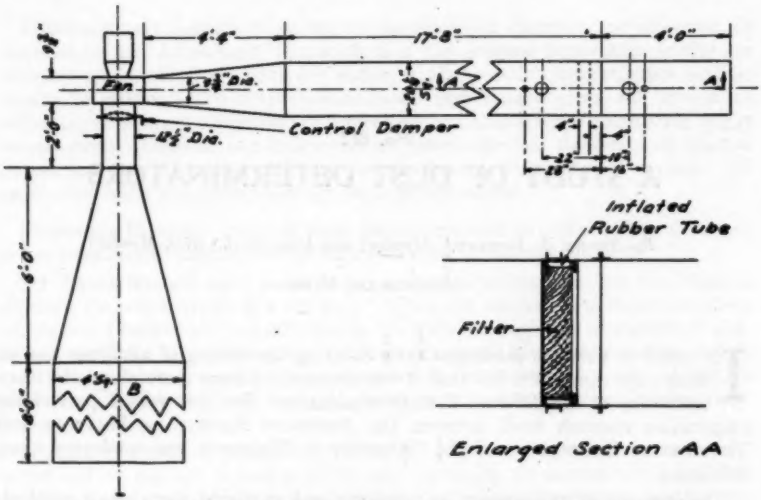

FIG. 1. PLAN VIEW SHOWING GENERAL ARRANGEMENT OF APPARATUS

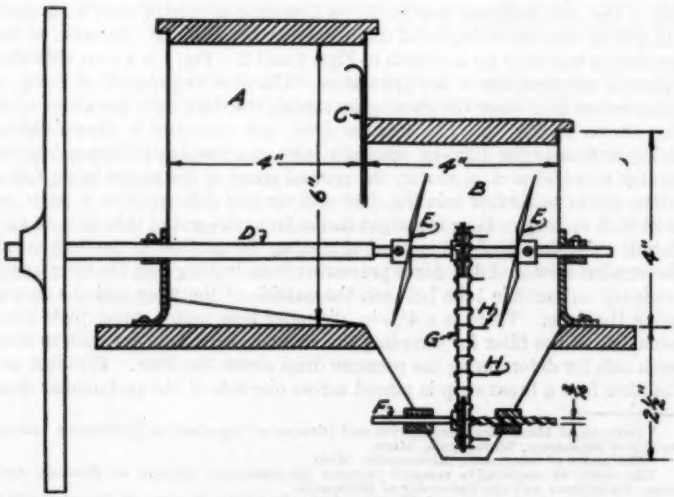

FIG. 2. DUST DISTRIBUTOR

five properly spaced holes are drilled through this brass strip. These holes are used for inserting a pitot tube to determine the velocity of air. The pressure drop across the filter is taken by means of an Ellison gage and the pitot tube readings are taken with a Whalen gage.

In order to get a continuous and uniform dust mixture, an apparatus as shown in Fig. 2 was built and placed near the entrance of the dust mixing chamber. This apparatus consists of two chambers, *A* and *B*. The first a receiving chamber for the dust and the second an agitating or mixing chamber in which the dust is thoroughly stirred up and from which it is uniformly discharged to the inlet or dust mixing chamber for the fan. The two chambers *A* and *B* are separated by a

Table 1. Variation Obtained with the Constants 1.18 and 1.26

Constant 1.18			Constant 1.26		
Value	Variation	% Variation	Value	Variation	% Variation
1.263	0.086	+ 7.3	1.77	0.43	+32.0
0.894	0.283	−24.1	1.58	0.24	+17.9
1.396	0.219	+18.65	2.04	0.70	+52.0
1.183	0.006	+ 0.51	0.83	0.51	−38.0
1.025	0.152	−12.92	0.75	0.59	−44.0
1.212	0.035	+ 2.98	1.25	0.09	− 6.7
1.267	0.094	+ 7.65	1.55	0.21	+15.6
			1.48	0.14	+10.4
1.177	Average		1.31	0.03	− 2.2
			1.28	0.06	− 4.5
			1.00	0.34	−25.3
			..	..	....
			..	..	....
			0.95	0.41	−30.6
			1.97	0.37	+27.6
			1.15	0.19	−14.2
			1.17	0.17	−12.7
			1.34	Average	22.3

sliding partition *C* which serves to regulate the level of the dust in the chamber *B*. A rotating shaft *D* carries two propeller shaped vanes *E* which serve to mix the dust and carry it from chamber *A* to *B*. A second shaft, *F*, in the lower section of chamber *B* is driven from *D* through sprocket wheels and chain *G*. The links of the chain *G* carry pins *H*, which assist in stirring up the dust and keeping it aerated. The slide *C* is adjusted to keep the level of the dust in chamber *B* below the top of the sprocket wheel. The right end of the shaft *F* is provided with a screw or spiral which carries the dust through the bearing and discharges it from the mixer.

This distributor is placed in the outer end of the dust chamber and discharges the dust directly in front of a 12-in. disc fan which thoroughly mixes it before it leaves the dust chamber.

It must be borne in mind that the object of the whole device is to test dust determinators and not to test the different types of air filters. For this reason it is not essential at present to consider the types of filters used.

The first set of experiments was made using the A-A Determinator. This instrument was introduced by Anderson and Armspach and described in the Trans-

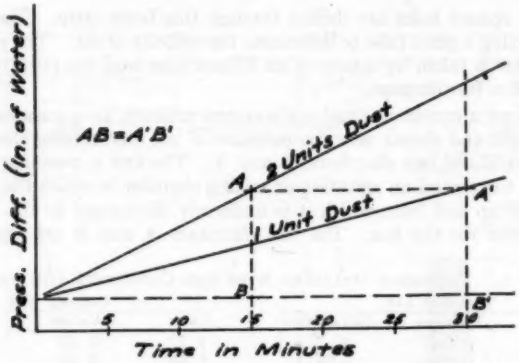

FIG. 3. RELATION BETWEEN DUST UNITS AND FILTER RESISTANCE

ACTIONS of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Volume 28, page 221. In this work one of the determinators was used with the dust distributing apparatus described and also a study was made of the data as obtained by Miss Ingels in her work at the Bureau of Mines Laboratory and reported in the TRANSACTIONS, Volume 30, page 121, and also Volume 31, page 67. The results obtained by Miss Ingels are particularly good for this study as she used six dust determinators and obtained six simultaneous samples from the same air. By this method some of the irregularities in samples were eliminated which must necessarily occur where samples are mixed at different times.

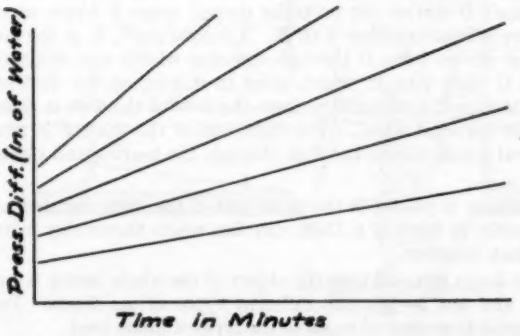

FIG. 4. RELATION BETWEEN INITIAL PRESSURE AND RATE OF INCREASE IN FILTER PRESSURE

In Miss Ingels' work referred to, she developed as a final equation

$$\frac{226.76}{(\text{Initial Press.})\,1.18} - \frac{226.76}{(\text{Final Press.})1.18} = \frac{K}{(\text{Initial Press.})\,1.26}$$

in which K was considered as a measure of the dust content of the air and $\frac{K}{10}$ was designated as the A-A dust unit. The dust chart is a graphical representation of this equation. On checking over the data the greatest variation seemed to be

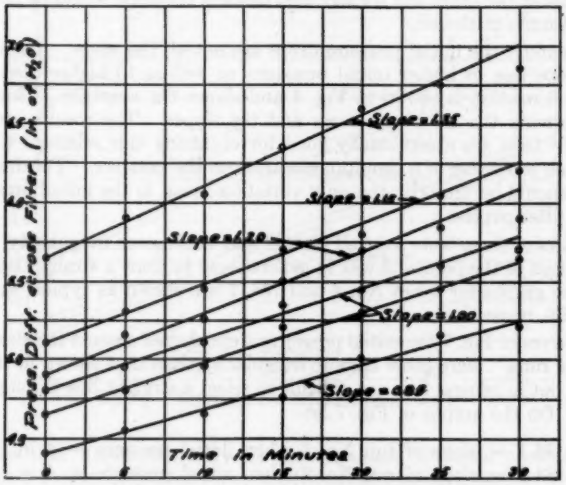

FIG. 5. RESULTS OF TEST SERIES NO. 4

with the constants 1.18 and 1.26. The data were plotted and a variation in constants obtained as shown in Table 1.

It would seem that these variations would seriously affect the accuracy of a dust determination.

From a study of the characteristics of the determinator and from the data obtained by Miss Ingels the following method has been developed which appears to have some merit and may be called a graphical method. This was developed on the following principles.

First, if the dust content in a sample of air remains uniform the pressure difference across the filter paper plotted against time gives a straight line.

Second, when simultaneous tests are run on the same air with filter papers of different initial pressures, the slopes are different for each paper, the higher the initial pressure the greater the slope.

Third, chemical filter papers are highly efficient in removing dust from the air passed through them. (The efficiency has been found to approach 100 per cent.)

If all filter paper had the same initial pressure difference, the problem would be comparatively simple. Referring to Fig. 3, if two samples of air, one containing one unit of dust and the other two units of dust are passed through the same filter paper, it is evident that the air with two units will increase the pressure difference across the filter paper the same amount in 15 minutes as the air with one unit of dust will increase it in 30 minutes. Or, in other words, the slope of one line would be twice that of the other and for any dust content the slope would be proportional to the dust units of the air.

Unfortunately, the initial pressure drops are not all the same. There is an increasing slope due to higher initial pressures as well as to higher dust contents. This general relation is shown in Fig. 4 and shows the necessity of knowing the relation between the initial pressures and the slopes. The results obtained by Miss Ingels' tests are exceptionally good for obtaining this relation, there being 9 series, each consisting of 6 simultaneous tests on the same air. The dust content, therefore, should be uniform, the only variation being in the initial pressure drop across the filter papers.

The results of these tests were all plotted and while some irregularity was noted in the position of the points, it was in general easy to draw a straight line through them. The graphs for series No. 4 and No. 7 are shown as typical examples in Figs. 5 and 6, respectively.

In the curves of Fig. 7 the initial pressures were plotted against the slope for each series of six runs. Here there is more irregularity than that shown in the preceding curves but in general it is not difficult to select a straight line through each set of points. On the graphs of Fig. 7 let

S4-1 = slope of run No. 1 when initial pressure = 4 in.
S4-2 = slope of run No. 2 when initial pressure = 4 in.
S4-3 = slope of run No. 3 when initial pressure = 4 in.
S5-1 = slope of run No. 1 when initial pressure = 5 in.
S5-2 = slope of run No. 2 when initial pressure = 5 in.
S5-3 = slope of run No. 3 when initial pressure = 5 in.

It then follows from the theory that

$$\frac{S4\text{-}2}{S4\text{-}1} = \frac{S5\text{-}2}{S5\text{-}1} \text{ and } \frac{S4\text{-}3}{S4\text{-}1} = \frac{S5\text{-}3}{S5\text{-}1}, \text{ etc.}$$

or rearranging these equations we obtain

$$\frac{S5\text{-}1}{S4\text{-}1} = \frac{S5\text{-}2}{S4\text{-}2} = \frac{S5\text{-}3}{S4\text{-}3} = \frac{S5\text{-}4}{S4\text{-}4}, \text{ etc.} = K.$$

Or stated in words, the ratio between the slopes at any given initial pressures is the same for any dust content. In order to check this from the curve, the constant K was determined for the slope of 4- and 5-in. initial pressure. The results of this determination are shown in Table 2.

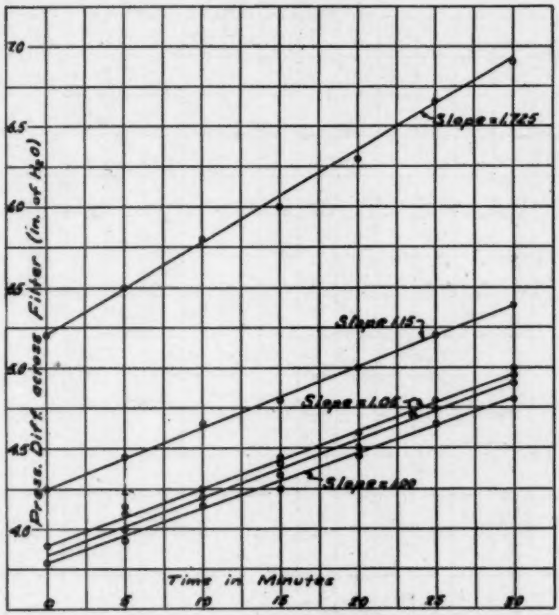

FIG. 6. RESULTS OF TEST SERIES NO. 7

This shows that the relation between the slope and the initial pressure for any dust content is a straight line for which the following relation holds:

$$\frac{\text{slope at 5-in. initial pressure}}{\text{slope at 4-in. initial pressure}} = 1.38$$

Obviously there are any number of such lines, one for each dust content. Any one of them may be used as a standard in determining the relative dust content.

TABLE 2. RESULTS OF DETERMINATIONS OF THE CONSTANT K FOR THE SLOPE OF 4- AND 5-IN. INITIAL PRESSURE

Run No.	Slope at 4" I. P.	Slope at 5" I. P.	Slope at 5" I. P. / Slope at 4" I. P.	% Variation from Mean
1	2.54	3.54	1.39	0.72
2	0.33	0.44	1.33	3.6
3	7.58	9.04	1.19	13.8
4	0.75	1.10	1.47	6.5
5 & 6	0.51	0.74	1.45	5.1
7	1.12	1.62	1.45	5.1
8	no line can be drawn	...	...	...
9	1.38	1.90	1.38	0
			Average 1.38	

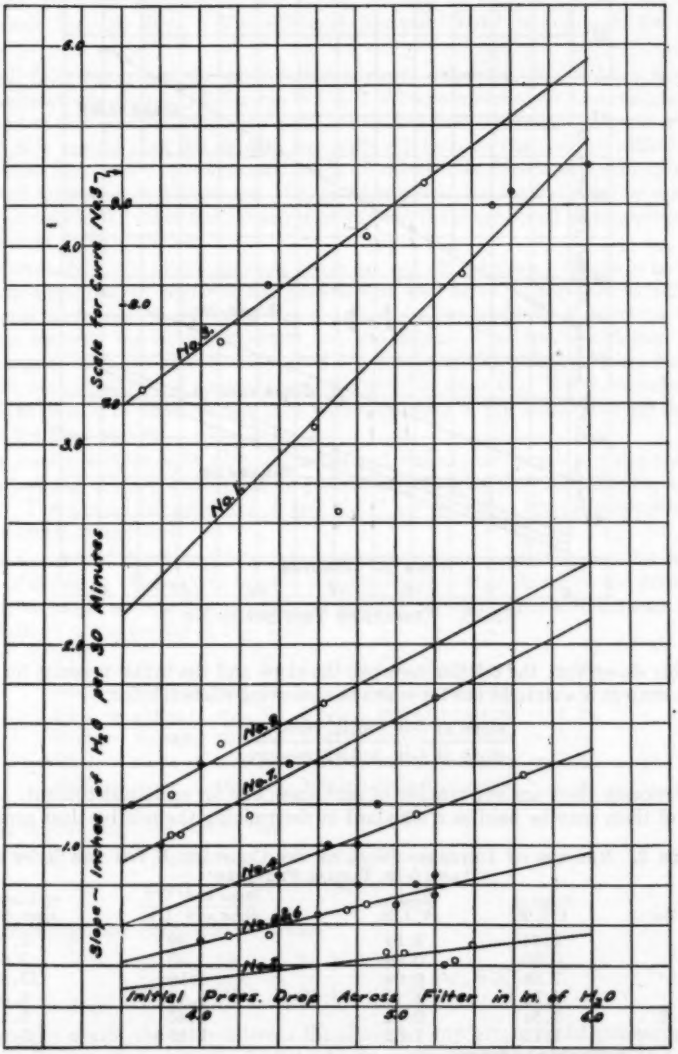

FIG. 7. CHART INDICATING RATIO BETWEEN SLOPES AT ANY GIVEN INITIAL PRESSURES ARE SAME FOR ANY DUST CONTENT

Table 3. Summary of the Comparisons between the Dust Content as Determined by the Two Methods for Each Series

Col. 1 Series No.	Col. 2 Dust Units by Proposed Graphical Method	Col. 3 Dust Units by Ingels' Method	Col. 4 Col. 3 x $\frac{102}{7.2}$	Col. 5 Per Cent Variation Col. 4 and Col. 2
1	188.0	12.2	173	− 8
2	22.2	2.4	34	53
3	511	16.9	240	−53
4	58.6	5.0	70.0	19.5
5	40.3	3.9	55.2	32.6
6	38.0	3.6	51.0	34.2
7	78.6	6.2	87.9	11.8
8	106	7.1	100.5	− 4.2
9	102	7.2	102.0	0

Since in series 9 the value of K is exactly 1.38, this will be used as a standard reference in determining the dust content of the other tests.

The relative dust content of the air used in Miss Ingels' 54 determinations was calculated using series No. 9 as a reference. The dust contents so calculated for the 6 determinations in any one series should be the same. The average variation obtained by this method was 4.42 per cent with the distribution as follows:

1 value	13.5 per cent
4 values between	10 and 11 per cent
3 values between	8 and 10 per cent
13 values between	5 and 8 per cent
30 values between	0 and 5 per cent
3 values discarded and considered experimentally inaccurate.	

A similar comparison of the dust units as determined by Miss Ingels' method gives an average variation of 4.66 per cent with a maximum of 16.6 per cent and a distribution about the same as shown above.

Table 4. Dust Constant Determined from Graph in Fig. 6 and the Standard Slope

Initial Pressure	Actual Slope	Standard Slope	Dust Content Proposed Method	Per Cent Variation	Dust Content Ingels' Method	Per Cent Variation
6.68	2.40	2.76	87.0	7.4	7.9	0
6.625	2.355	2.73	86.2	7.7	8.2	3.8
6.625	2.355	2.73	86.2	7.7	8.9	12.7
6.43	2.37	2.63	90.0	11.1	8.4	6.3
6.42	2.30	2.62	87.8	10.4	9.7	22.7
6.16	1.79	2.49	71.9	12.2	7.5	5.1
6.10	1.77	2.46	71.9	12.2	7.4	6.3
6.03	1.75	2.42	72.3	11.7	7.9	0
5.275	1.385	2.04	68.0	16.0	6.4	19.0
4.58	1.25	1.68	74.4	8.1	8.1	2.5
3.95	1.11	1.36	81.6	0.8	7.4	6.3
3.30	0.96	1.02	94.1	16.0	7.1	10.1
			81		Av. = 7.9	

In Table 3 the second column shows the dust content as determined by the proposed graphical method and the third column as determined by Miss Ingels' method. The fourth column shows the dust units of the third column converted into the same units as those of the second column for comparison and the fifth column shows the percentage variation.

From Table 3 it will be noted that even though each system in itself shows reasonable uniformity, there is a marked variation between the dust content as determined by the two methods. Enough experimental work has not been finished to establish the complete relation between the two methods, but in general for dust contents below 102, which was taken as a basis for comparison, the proposed system shows a lower dust content and for contents above 102 it shows a higher dust content. This relation between the two methods is fairly close to a straight line for the lower dust contents.

In order to further check the theory developed from Miss Ingels' data a series of twelve determinations was made holding the dust content as nearly constant as possible. Inasmuch as only one A-A Determinator was available, the time of taking the tests spread over several days and it is quite probable that some variation existed in the actual dust content of the air for the different tests. This would account for the fact that the variations in this series were somewhat greater than those calculated from Miss Ingels' data which were taken by simultaneous readings from the same air sample. The results of these tests are shown graphically in the curves of Fig. 6, in which each individual test is plotted with pressure difference across the filter as ordinates and time in minutes as abscissae. From this graph and the standard slope the dust constant was determined as shown in Table 4.

From Table 4 the average dust content for all tests was 81 units with a maximum variation of 16 per cent and an average variation of 10.1 per cent. The average dust units as calculated by the Ingels' method are 7.9, which if converted over to the new method of units gives 112.0, instead of an average of 81.

This second series of tests shows a greater variation than those determined with six different samples of the same air as would be expected. The variation in the dust content, however, is not serious when determined by either method when considering the fact that there is probably a variation in actual mixture for the different samples. The fact that each method seems to give reasonably consistent results when taken by itself, and yet when the two methods are compared there are such wide variations, would indicate that further experimental work must be done to check results. It is the purpose to continue this work and also include other dust determinators.

DISCUSSION

S. SYLVAN (WRITTEN): The art of air cleaning is certainly greatly hampered by the lack of any recognized method of testing cleaning efficiencies. We are very glad to know of Professor Rowley's tests and we hope that your combined efforts will soon produce something definite along these lines.

Before going into any comments on this present paper, I would like to mention some general points on the requirements of a cleaning efficiency method.

The chief requirement is, of course, that the cleaning efficiency obtained should

be a real measurement of the usefulness of the air filter. A dust count efficiency, for instance, is a measurement of the performance of the air filter but is no measurement of the usefulness. To illustrate this statement I may mention that the cleaning efficiency of any air cleaner is different for every different kind of dust. An air cleaner may have 95 per cent efficiency on large and heavy dust particles but next to no efficiency on very small and light ones. In this case a dust count would give, for instance, 100 large particles and 100 small ones on the fresh air side and 5 large particles and 100 small ones on the clean air side, and the efficiency accordingly would be $47^1/_2$ per cent. As a rule only the large particles will cause any trouble or damage and the usefulness of the filter accordingly is 95 per cent instead of $47^1/_2$ per cent.

Neither weighing methods are quite reliable on account of the dust particles not being troublesome in proportion to their weight.

The property of dust that causes most of the trouble is the settling tendency which can be measured by means of the settling velocity. The actual amount of trouble in any volume of air then will be proportionate to the sum of the settling velocities of all dust particles contained in this volume.

The settling velocity is proportional to the square of the diameter of a dust particle and to the specific weight of same. The shape of the particle will also have some influence. The main requirement of a correct cleaning efficiency method is that it should be based on these properties of a dust particle.

None of the methods known will fill this requirement and I doubt whether a practical method can be developed to do so. In such a case the one method should be preferred that corresponds closest to this theory.

The Anderson-Armspach method is simple and seems to give fairly consistent results. However, it has obvious drawbacks. Fine dust has a greater clogging effect on filter paper than the heavy dust and will, consequently, affect the result unduly. In this connection I may point out that according to our experience it is perfectly impossible artificially to copy a natural dust condition. Especially small carbon particles have a great tendency to coalesce and form greater aggregates. Artificial dust contains no fine particles.

Some remarks in regard to counting methods have been mentioned in the above. In the actual operation, however, these methods do not show results as mentioned but will, as a rule, give a higher cleaning efficiency than the actual. The reason for this is the very primitive method of collecting samples that is commonly used with dust counters. Of course it is very optimistic to expect to catch in one single impingement particles that have escaped maybe several hundred impingements in the air filter. It has always been our opinion that samples for counting should be taken on filter paper. By doing so results are obtained that correspond closely to the above mentioned.

The Tufty method described in the JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS of January, 1927, seems to have several advantages. Thus, the particles are considered in proportion to the square of their diameters and the results are fairly consistent. Personally, I have never tried the method but I believe that with a sampling on filter paper it would give the best results of any one known.

The weighing methods correspond closely to the theory but are very impractical, really to such an extent that we have decided to abandon them. Unless the weighings are made with the utmost care consistent results cannot be obtained. Furthermore, the impingers or filter papers used for sampling must be kept in operation for such a long time that the dust holding qualities of the filters will have an influence on the cleaning efficiency obtained.

We are trying to develop an electric method for measuring cleaning efficiency based on the difference in conductivity of clean and dusty air. This method will not agree perfectly with the theory but will permit instantaneous and direct readings of cleaning efficiency.

As a summary we would recommend to the Society that the above settling velocity theory be considered in selecting a standard method and code for testing cleaning efficiency of air filters.

W. H. CARRIER (WRITTEN): I have read with interest Prof. Rowley's paper. The method used by Prof. Rowley in taking the change in the slope of the line is excellent. Unfortunately, it seems to show that there is no constant relation between the slope and the initial resistance which would make this instrument reliable for quantitative analysis.

There is, however, one very important requisite in a dust determinator for use in quantitative tests on air cleaners which has so far been entirely overlooked in most of the studies of dust determinators and, in fact, in most of the devices that have been gotten out.

First: It must be recognized that there are three distinct types of solid impurities in the air which behave quite differently in relation to the persistance in the air and also as to the possibility of their elimination by mechanical impact, filtration or electrical precipitation. Dust particles are those which apparently are heavier than air. That is, no matter how fine they are they will eventually separate out by gravity and tend to a large extent to be removed by impact or by centrifugal effect.

Second: There is what may be termed *Fume*, which is the designation given by Dr. Drinker in his studies of dust determination, which will separate out from the air by impact or filtration, but not by gravity. These are much smaller particles than the so-called dust particles.

Third: We have smoke which consists of almost ultra-microscopic particles and behaves very much as a gas in the air, although they are actually solid particles. These cannot be removed at all by gravity, nor to any great extent by impact, nor even completely by infiltration through filter paper, as may be proved by blowing cigarette smoke through a filter paper and noticing the cloud of smoke that passes through. A great proportion of the weight, of course, is removed. This consists largely of the heavy carbon particles and the condensible vapors together with the smoke particles which are precipitated with the condensation. The smoke can probably be removed most successfully by electrical condensation and precipitation. Now it is obviously quite foolish to test the removal of true smoke particles in an air-cleaning device which operates by impact.

At the present time there is no air cleaner on the market which does not operate by impact, even cloth filters, which work the best after they have built up a slight film with filtration dust on their surface, probably operate primarily by impact be-

cause the interstices are such that they would allow any of the smaller particles through if it were not for impact on succeeding surfaces. We have no true filters like filter paper, nor would they be practical in an air installation.

We have, it is true, electrical precipitation used in undustry which is understood to be exceedingly effective in respect to dust, fume and smoke. As I see it, Standard air cleaners used in ventilation work can only be expected to remove dust, fume to some extent and smoke practically not at all. Cloth filters of close weave will remove both fume and dust almost perfectly but not smoke so it would seem rather folly to test these for character of impurities which they are not adapted to or intended to remove. For example, if you first remove all dust from the air and then add fume and smoke you would get a very poor showing for any commercial air-cleaning device (using an electric precipitator, or even a paper filter for determining the percentage of removal).

Viewed from another standpoint, there is always a defect in the filter resistance method of testing any types of air purifiers. I think it has been pretty clearly shown by Miss Ingels' work that the resistance built up by dust or other impurities on the filter depends in a large measure on the character of the dust. Now most air purifiers are necessarily selective in their dust removal as has already been pointed out, easily removing the heavier particles and being less efficient in removing the smaller particles, especially such as may be designated as fume or smoke.

Therefore, if you are to use two resistance tests, one on each side of a cleaner, you will be getting a resistance effect on one side due to one character of dust and on the other side of the cleaner a resistance effect due to an entirely different character of dust. Therefore, the two tests are not at all comparable. For this reason, and for the other reasons given, I have always claimed that the filter resistance method is absolutely useless in testing the performance of commercial air-cleaning devices.

One of the best services that Prof. Rowley's committee can do is to either approve or disapprove this. A study of mere dust determination alone is entirely inadequate for this purpose as I have just attempted to show.

Theoretically, an impact cleaning device should have its efficiency tested by a device using the impact method, such as for example that outlined by Goodloe in a paper before the Society or by some other device of a similar character. The basis of comparison is most simply made on the basis of weight removal for at the present that is the only standard except the dust count which is generally comprehended. Of course, so far as a weight comparison is concerned the dust count method may be hardly comparable although it would be very interesting to set up some standard cleaning device using some standard type of dust and method of density production and using the three types of dust determinators for comparing the efficacy of removal. First, the impact weight method, second, the dust method, third, the filter resistance method.

Then the character of the dust should be changed if possible and a similar test made. Of course, there should also be a use for the filter weight method and the electrical precipitation method.

Primarily, as I take it, the committee conducting the tests should have two distinct viewpoints in mind.

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First: To define the function of commercial air-cleaning devices of different types and to recognize the limitations as to their performance.

Second: To test various devices for determining dust removal with the object of selecting one which will most accurately and conveniently indicate the efficacy of such devices within the scope of their possibility.

Third: To standardize the type of dust to be used in shop tests; for unless this is standardized and unless shop tests are made, there can be no standard of performance and no two tests under different conditions of dust density and dust character will agree.

R. C. THOMPSON (WRITTEN): It is rather an ungrateful thing to criticize a job which is admittedly only half done, as is the case in the work of Messrs. Rowley and Beal on Dust Determinators. I personally am extremely interested in this work and very glad that it is being done. I am also glad that they have picked on the A-A determinator for the extensive work which they are doing, but there are several features which I would like to see worked out of which there is no apparent mention.

The studies made to date seem to be largely limited to setting an arbitrary unit of dustiness derived from the characteristics of the instrument at hand. This seems to me to be putting the cart before the horse. One should know first what one is trying to measure and then find out what the instrument is showing.

In general there are two ways in which the concentration of one material in another may be expressed. The first is parts by weight, and the second, parts by volume. The third which I might mention here due to the fact that it is employed in so many determinators, is in particles of matter in unit volume or weight of the other material. Of course if all particles are of equal size or in a large number of samples the average particle is the same size, which is immediately reducible to parts by volume, or if the average particle is of the same weight it is reducible to parts by weight and, therefore, this expression is really a derivative of one of the other two.

It seems to me that the thing we are primarily interested in on most jobs is the dust content of air in parts by volume. The A-A determinator is one of the few methods which is calculated to show this relation. Therefore, it would seem to me that the method of attack would be to measure the volume of dust introduced into the air by the dust mixer and then see what relation the increase and decrease of this volume bears to the readings taken by the determinator, especially studying the effect of the varied range of particle sizes. In this way units could be selected which will have a physical concept in back of them rather than purely arbitrary constants which have little or no meaning aside from the instrument by which they are measured. Such a procedure also has the advantage of producing readings which can be correlated with readings made by other methods and other instruments a thing which is almost impossible with a unit based upon the characteristics of one individual instrument.

Another thing which I would like to mention, although it is doubtless in the minds of the experimenters is the fact that in the field we are confronted with very small and very variable dust loads and what, above all, we wish to know is first, what dust load is permissible in air used for various specific purposes such as ventilation of offices, ventilation of electrical equipment, drying food stuffs, etc., and second,

what dust loads will be carried in the air, drawn through various types of air-cleaning devices when the incoming air is of a given quality. Furthermore, the apparatus to do this must be simple enough to be operated by a reasonably good engineer not specializing particularly in this work; sensitive enough to give readings within a reasonable limit of error on the very light dust loads which are met in the average ventilating job; inexpensive enough so that the architect or consulting engineer can afford to own it, and lastly, the instrument must be portable so that it can be used on installations in the field.

These are stringent requirements, but they are requirements which must be met if we are going to have a code for testing air filters which will be of real value in the practical selection of air-cleaning devices.

PROFESSOR ROWLEY: I think the work is fairly well presented in the paper and represents a progress report of the research on one of the dust determinators. Several of these are to be used with the hope of reaching some conclusion as to the proper method of measuring dust in the air. The important part as far as the committee is concerned is to get constructive criticism on the method, or suggestions of any other methods available. Much of it might preferably be written so that the committee can have it to go over and make the most of.

No. 813

METHODS OF AIR DISTRIBUTION

By L. L. Lewis,[1] Newark, N. J.
MEMBER

IT IS natural, at the present time, for any discussion of the subject of air distribution methods to turn to the problems met in the designing of air conditioning apparatus for theatres and auditoriums.

Given a room, the four walls and ceiling of which are plain, unbroken surfaces, an evenly distributed heat loss or gain, and the freedom to run ducts without regard to appearances, the problem of *perfect* air distribution becomes a simple one. At the other extreme, such as is met in an elaborately decorated theatre, the results obtained in many installations show that there is yet much to be learned. It is plainly the duty of the architect to reduce the wasted space behind furred walls and hung ceilings to the minimum, and it is also plain that in many cases the limitations so imposed are beyond those with which the engineer is now prepared to contend.

Complete cooperation of engineer and architect through a sympathetic understanding of mutual problems is essential to complete success.

It is best to begin with the admission that the air handled by the fans steadfastly refuses to recognize the authority of all of the *trained arrows* which are placed on the blueprints to show it where to go.

Returning to the room with four square walls it becomes evident that one more feature is desirable for perfection. The duct, through which the air approaches the first outlets, should run straight and square for such a length that the flow will be uniform over the entire cross section of the duct. The turbulence caused by a poorly designed elbow, offset or conversion section, may not only spoil an otherwise perfect outlet, but also cause an unnecessary loss of pressure and an appreciable contribution toward an objectionably noisy system.

Humidifying, as it grew out of factory or industrial heating, became the first phase of air conditioning. The humidifying system required the first large development of the dual distributing system; that is, a single system of ducts and outlets which would distribute either hot or cold air equally well. The hot air was easy to distribute because it was lighter than room air and had a natural tendency to float overhead and spread in all directions. The cold air being heavier than room air had to be spread mechanically, otherwise it would fall or spill to

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Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, West Baden, Ind., June, 1928.

the floor at a velocity and with a disturbance, both of which increased as density of the air delivered became relatively greater than that of the room air.

While this problem now seems simple, many mistakes were made in the first systems. The first occurred in the old heating outlets, an inheritance, such as in Fig. 1. This outlet was part of an exposed duct system in a rectangular room, as shown in the upper left margin. The blow ordinarily was from 60 to 80 ft. and at an angle of 45 deg. forward. The velocity by which the area of the outlet was calculated ranged from 600 to 1200 ft. per min.

Such a system was quite satisfactory for distributing hot air, but with the cool air required for humidifying, a great many troubles soon appeared.

This outlet was very sensitive to duct velocity and to the direction of approach.

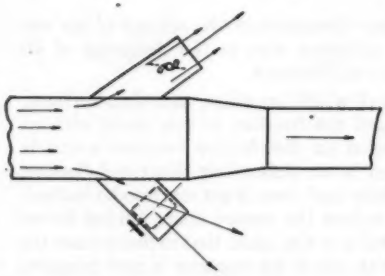

FIG. 1. OLD STYLE OUTLETS OF AN EXPOSED DUCT SYSTEM

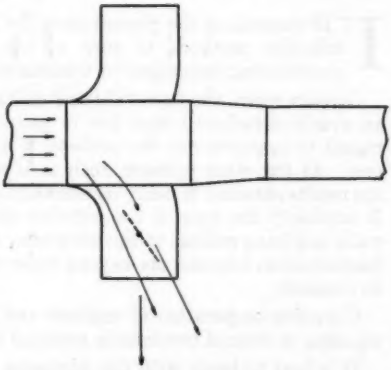

FIG. 2. MODIFICATION OF OLD OUTLET

The directional arrow meant nothing to the air which, when the axis of the customary damper was horizontal, would tend to parallel the duct. Beyond and near an elbow the outlet on the inside of the duct will become an inlet because of the vacuum created by the uneven flow as the air stream swings to the far side. The companion outlet on the far side would receive full velocity and pressure and deliver a volume of air far in excess of its intended rating.

When this was corrected by adjusting the dampers, the velocities through the restricted openings were greatly increased and frequently the air currents were deflected downward either directly or indirectly by some inconvenient beam, girder or column. The remedy for this was complete closure, which in turn increased the static pressure in the duct and brought another outlet into the troublesome class. The progressive action thus started, has in many instances done great harm to air conditioning.

The intensity of such trouble was usually in some direct relation to the volume of air per outlet and in some indirect relation to the length of the outlet. By greatly increasing the number of outlets and so lengthening them that a definite control

of air direction was assured, good results could be obtained, but at considerable cost. A modification of this outlet used in greater numbers and on a longer duct is shown in Fig. 2 though this was no better than the other.

In distributing cool or cold air, better results have been obtained by spreading the air fan shaped overhead and having it descend gently by virtue of its greater density. This principle has been well carried out in a multi-port outlet, a diagrammatic view of which is shown in Fig. 3.

The outer halves of the deflecting vanes are stationary. The inner halves are hinged to the outer and so linked that they serve the double purpose of dampers and deflectors. Such a design permits the use of duct velocities and static pressures fatal to the plain outlet, because of the relatively great length of the passage from the duct to the point of delivery. In ordinary practice, the leading vane

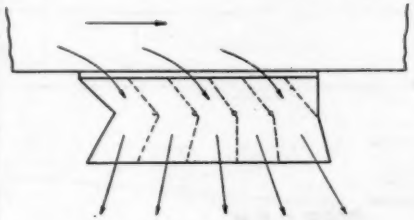

FIG. 3. DIAGRAMMATIC VIEW OF MULTI-PORT OUTLET

can be made to deflect the air through an angle of 135 degrees from the center line of the duct in which case the air actually follows the arrows.

In theatres there are two widely different types of distribution, the up-system and the downward-system.

The up-system, in the practical application of which air is delivered at the floor line, was developed first. Coming from a plenum or ducts beneath the floor, the air is deflected horizontally by mushrooms or aisle hoods and occasionally by registers in the rise of the steps forming the various levels in the balcony. Upon leaving the floor level, the flow is upward to exhaust or return openings, which are conveniently located overhead.

Such a system is good for heating and may be satisfactorily used for ventilating with tempered air, but is unsatisfactory for cooling. The degree of this failure may be better understood when it is known that in the average theatre, cooling is required in midwinter when about three-quarters of the seats are filled. Even when heating, the up-system fails to create circulation, that third important quality, and leaves the air dead in the theatre.

The difficulties in delivering cold air with this system are obvious. A certain amount of heat must be absorbed if satisfactory temperatures and humidities are to be maintained. If the cost of the system, the power and steam required for operation and the space for apparatus and ducts are all unlimited, then such air

volumes may be delivered as to keep foot temperatures and head temperatures within suitable limits, but such is rarely, if ever, practicable. A full appreciation of the appeal of the picture and the attraction of the theatre is possible, only to the close and interested observer, who spends enough time to note that not a few regular patrons come prepared with paper and what-not with which to insulate their feet against the cold streams of air that hug the floor.

The balcony slope adds certain complications. In a number of recent designs,

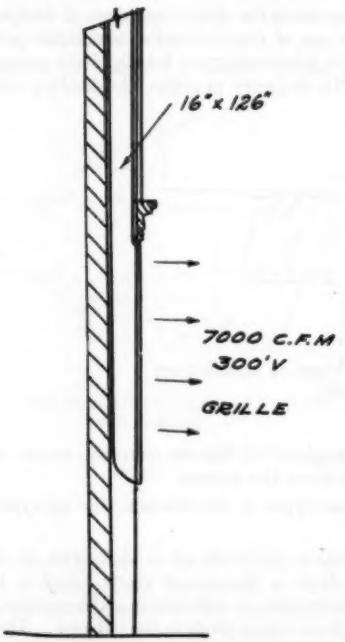

FIG. 4. OUTLET FOR SHALLOW SPACES WITH AIR FLOW INDICATED

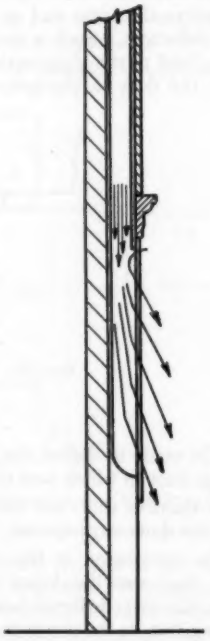

FIG. 5. HOW AIR ACTUALLY FLOWS FROM OUTLET

the tendency of the lowest mushrooms to deliver the greatest volume has been overcome by an elaborate subdivision of the balcony plenum. This, however, still leaves a portion of the orchestra exposed to a spill of cold air, which cascades down the balcony slope because of its greater density.

The first attempts at cooling with refrigeration during the summer months were made by simply adding a direct expansion surface air cooler to an up-system. These were important steps in the development of theatre cooling and a valuable contribution. Vastly improved summer conditions were obtained with installa-

tions that were considered successful, but which served more than anything else to prove that the up-system was not suitable for cooling.

The public was soon to learn that comfort in summer as well as in winter could be provided upon demand. As a result, the up-system has been generally abandoned for all high-grade cooling installations.

While the downward system is by no means new, it is only during the last few years that the use of refrigeration for cooling has brought it forward for intensive study and development. This system first appeared as a sidewall outlet heating system. For the small, narrow movie theatre this worked quite well and was considerably less expensive than the up-system, because the expensive plenum

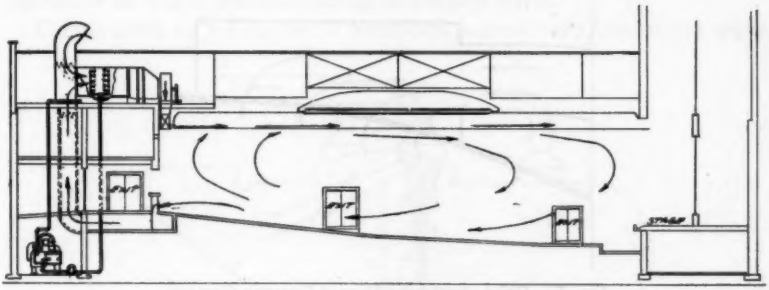

FIG. 6. SYSTEM OF REAR WALL DISTRIBUTION

was not required even if space for it was available. Some ingenuity of design was required to heat successfully with downward circulation for it was necessary to exhaust the cold air from the floor level. It was discovered that an elaborate mushroom exhaust system was by no means necessary.

As theatres grew larger and incidentally wider, the deficiencies of this system became apparent and now the reasons are obvious.

Increasing the width of the theatre increases the length of the blow from the supply outlets. The length of blow obtainable increases with the volume of air delivered from a single outlet, the velocity of delivery, the height of the outlet above the floor and, to some slight degree, with the relative density of the air delivered. Whether the approach to the outlet is from above or below, the delivery must be sufficiently horizontal to avoid striking either the people or a deflecting obstruction on the ceiling. Depth of outlet is required to obtain this deflection and the engineer must in this case agree with the architect that shallowness is essential, both for the conservation of sidewall space and for appearance.

These two things are, therefore, in direct conflict and the result is an outlet such as is shown in Fig. 4, which was selected from a set of plans just recently sent out for bids. The volume, 7000 cu. ft. of air per min., is ample for any blow that might be required. Note the four arrows. The engineer has passed his responsibility on to the contractor, and with these four arrows indicates that

the flow through the grille is to be horizontal in direction and of uniform velocity from top to bottom.

There are no conceivable baffles or guide vanes of sufficient depth to deflect the air horizontally from this outlet and, at the same time, shallow enough to permit the down-coming air to pass to the lower part of the grille.

What actually occurs is shown in Fig. 5. Note that a fifth arrow indicates that under the influence of the enlargement in cross section, a small volume of air is drawn into the outlet which later emerges and joins the downward flow toward the bald heads of the audience.

Fortunately, there is a partial remedy. If the back of the grille is cut off so as

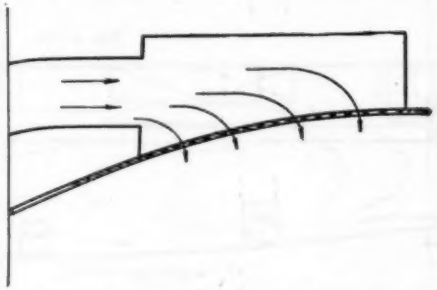

FIG. 7. CHARACTERISTIC USE OF CEILING GRILLES

to build up the outlet velocity and grille resistance, the direction of flow will approach the horizontal. But to obtain proper direction, the velocity through the openings must be several times the velocity of approach, which would result in a noisy outlet.

It is interesting to note that at an outlet, room air is drawn into the stream and mixed with it, resulting in an induced secondary circulation and raising the temperature of the air stream by dilution. As the outlet velocity is raised, this effect increases in relation to the kinetic energy of the stream, and a whirl or circulation is created with a horizontal axis.

The result, at velocities sufficient to blow half the width of the average 2000-seat theatre, is apt to be a return current along the breathing zone back toward the outlet. While less sensitive than the back of the neck, the side face is sensitive to a degree that makes such circulation decidedly dangerous.

Sidewall distribution, therefore, becomes increasingly difficult as the width of the theatre increases and space at the sidewall is increasingly conserved.

Relief from troublesome drafts is not to be had with low outlet velocities, but rather with velocities from outlets which will give control both of the direction and the intensity of the induced circulation. This has been effectively demonstrated in a rear wall distribution in which extraordinarily high velocities from outlets, unobstructed by grilles, carry cold air well over the heads of the audience to induce a return circulation in the opposite direction in the breathing zone.

A vigorous circulation is possible with this method, because the return current flows uniformly into the faces of the audience.

With this system contraction of the jet issuing from a converging nozzle draws large volumes of room air into the stream thereby warming or cooling it by dilution. The high velocities induce a large secondary circulation. Note the arrows in Fig. 6.

It is a difficult system to design as the size of the outlets and outlet velocity must be adjusted to the blow, which is quite sensitive to both. The subsequent interposition of a beam or an ornament by the architect or the failure of the engineer to discover such an obstruction is dangerous. Outlets that are too large or velocities that are too high are bad, but even worse is a low velocity which allows the air to spill before completing its intended travel.

Unfortunately for the downward circulation, a great many large ceiling grilles

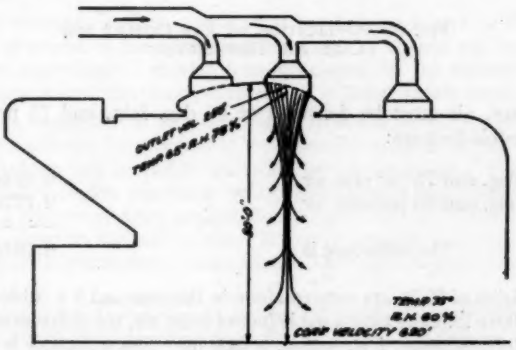

FIG. 8. COOL AIR INTRODUCED AT HIGH POINTS

have been used as outlets. The one shown in Fig. 7 is characteristic. The ceiling may be flat or slightly curved. The grille has a lattice or filagree pattern. Ordinarily, the clear area for air delivery varies from 40 to 60 per cent of the gross area.

The box may be a cone or a pyramid with air fed to it downward vertically from a drop pipe. Occasionally, something similar to the tuyère ring on a blast furnace feeds air, presumably from all directions. Outlet velocities are indicated by arrows and noted as ranging from 100 ft. per min. upwards.

Regardless of what the outlet velocity may be, such a ceiling grille cannot be successfully used as an outlet of a cooling system unless some means of horizontal deflection is provided, or unless they are made small in size, large in number and uniformly distributed.

In cooling a theatre, it is necessary at times to deliver air at temperatures 10 deg. below that in the theatre. If 75 deg. fahr. and 60 per cent is to be maintained

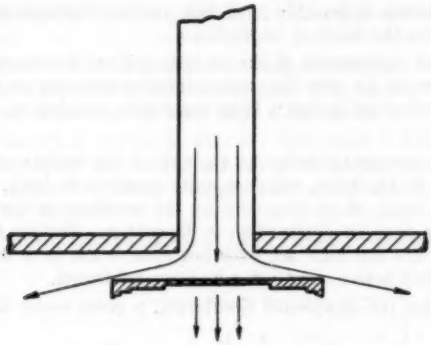

FIG. 9. APPLICATION OF PAN OUTLET FOR COLD AIR DISTRIBUTION

in the theatre, air must be delivered at 65 deg. fahr. and 75 per cent. The weights per cubic foot are:

65 deg. and 75 per cent air	0.0744 lb.
75 deg. and 60 per cent air	0.0729 lb.
The difference is	0.0015 lb.

Ceiling heights of 60 ft. are very common in theatres and if a cubic foot of outlet air weighs 0.0015 lb. more than a cubic foot of room air, the difference in the weight of the two 60-ft. columns, 1 ft. square, is 0.09 lb. This difference is equivalent to a pressure of 0.018 in. water gage. The air velocity corresponding to a head of 0.018 in. of water is 540 ft. per min.

Therefore, regardless of how low the velocity at this grille may be, the core of any air column not small enough to be completely dissipated before reaching the

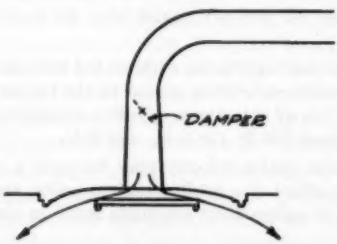

FIG. 10. OUTLET FOR HORIZONTAL DIFFUSION OF COOL AIR

floor line will reach the floor line at a velocity of 540 ft. per min. The air flow will be something like the arrow in Fig. 8.

If the ceiling is 80 ft. above the audience, our bald-headed friend will be struck with a column of cold air moving at a velocity of 620 ft. per min.

Such velocities are, of course, fatal to the satisfactory operation of the system in any manner except as a heating system. Cold air may be blown straight downward, but only in such small volumes per outlet that the core will become completely diffused into room air before reaching the breathing zone.

Circulation is highly desirable when it is under complete control and its temperature is first equalized with that of the room at all delivery temperatures. A movement of 150 ft. per min. in the breathing zone is permissible. There is no combination of temperature and humidity which can give satisfactory conditions unless accompanied by proper air motion to remove the body film and to give life to the air.

In using downward circulation with what has become known as the pan outlet system, it is practical to use a reasonable number of outlets and to increase the air per outlet accordingly. Having been developed for the delivery of cold air, this method has proved the most practical and is being widely applied.

The simplest application is shown in Fig. 9, in which the impact of the descending air current is taken by a screen of such restriction as to permit a part of the air to pass through and to deflect the other part horizontally. The screen may be omitted, but then the pan must be dropped farther below the ceiling. In a new theatre a somewhat more artistic design, as in Fig. 10, makes it possible to keep the pan closer to the ceiling line. It would be more accurate to call this a horizontal diffusion system for a good horizontal diffusion is essential to a successful application.

In concluding, the author desires to express his appreciation of the helpful advice and suggestions which have come from W. H. Carrier and from many of the men with whom he has the privilege of being associated.

His conclusions are:

1. That the engineer should place less dependence on the arrows in front of the grille and more upon his details of the necessary deflection vane behind it.

2. The engineer should educate the architect to a more complete understanding of the danger of placing deflecting surfaces or obstructions in the path of the air leaving the outlets.

3. That much is yet to be learned about air distribution through research and experiment as a very large part of our present knowledge is in the form of personal opinion.

DISCUSSION

B. S. HARRISON (WRITTEN): In reading over Mr. Lewis's paper, it occurred to me that the chart shown, Fig. A, might be of interest.

In setting up for test on a diffusing air nozzle, the object of the test being to ascertain the *carry* of the air, and plotting same velocity against distance from

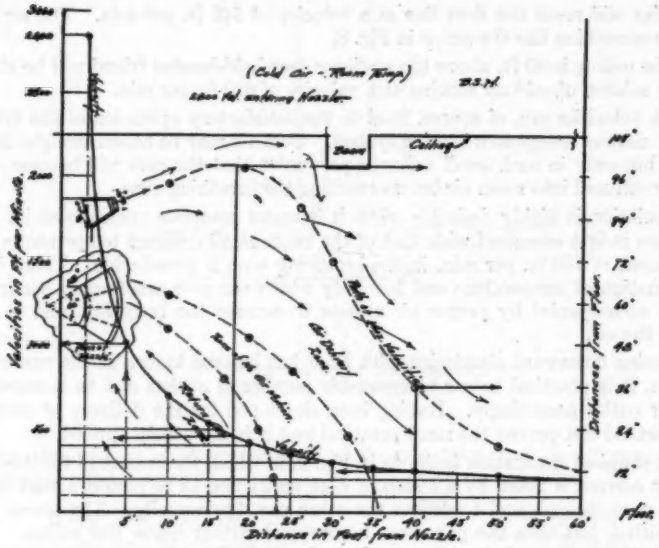

FIG. A. DELIVERY OF AIR WITH DIFFUSING NOZZLE AND EFFECT OF OBSTRUCTION

nozzle—the rig was inadvertently placed where a ceiling beam was in direct line of discharge. The result was the curve of path of maximum velocities. A surprising result of test was the zone of no air motion. The tests were made with a Bacharach sensitive ventura pitot instrument which gave velocity readings down to about 50 feet per min. with accuracy.

L. A. HARDING: This is a subject many of us are interested in and the paper brings out a fact that we have frequently observed in air-cooled theatres. I should like to ask Mr. Lewis if it is his practice to design the improved type of outlet employed in industrial work on a basis of static pressure in the main at the point where the outlet is heated and if that is true, would it not be necessary for the engineer to have some knowledge of the friction pressure loss through this type of outlet before he can intelligently use it? If that is so, would not the paper have a little more value to the industrial engineer if some actual figures were given so we could use this type of outlet and know what we are using?

L. L. LEWIS: I think it would, Mr. Harding, but the viewpoint which I took was rather elementary. There seemed to be so many interesting features which seemed to center upon the delivery of the air of greater density than that of the room, that it would be well worth while to consider that only.

Answering your question regarding the outlet, the best practice is to design a

duct system in which the loss in each successive run is taken care of by the conversion of velocity into static pressure. The outlet will not work satisfactorily where the velocity in the duct is extremely high, the top limit being slightly above 2500 ft. per min.; the static pressures required are very low.

The experience of Mr. Harrison is quite interesting. Its value is appreciated, because it is another bit of evidence to show the importance of the complete cooperation of engineer and architect not only in the installation of the air-distributing system but, also, in the elimination of interferences either in building construction or interior decoration.

No. 814

REFRIGERATION AS APPLIED TO AIR CONDITIONING

By R. W. WATERFILL,[1] NEWARK, N. J.

NON-MEMBER

THE PURPOSE of this paper is to point out the developments in progress for the adaptation of refrigeration, as formerly applied to ice making, to the more recently developed field of dehumidifying and air conditioning. It would, therefore, seem pertinent to compare the characteristics of the many developments available.

From an energy standpoint, refrigeration is the elevation of a given quantity of heat from one temperature level to a higher temperature level. In any given installation made for a fixed duty, the low temperature level is a specific and constant value, depending on the purpose and requirements of the installation. The high temperature plane to which the heat is to be pumped is the variable, which is governed by the character of the natural forces, which are used to remove the heat at the higher plane, and the extent to which these natural forces are consumed. The factors which fundamentally govern the ultimate temperature head at which the total heat involved must be disposed of, constitute the initial temperature of the cooling medium or condenser water, the quantity of condenser water used, and the efficiency of the condensing surface in removing the heat from the refrigerating medium with the lowest possible temperature difference between the refrigerant and the condenser cooling water. The power required to produce a ton of refrigerating effect with any refrigerating medium in any system, increases with the saturation temperature difference between the condenser and cooler vapors.

Refrigerating Requirements of Air Conditioning

Air conditioning, including dehumidification, passed out of the experimental stage long ago and has seen many instances of successful application within various industries.

While the refrigerating requirements for air conditioning involve the same basic principles as for other refrigerating work, there are differences which make it desirable to treat air conditioning refrigeration from a different point of view than that considered in ice making or other low temperature work. The differences are

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[1] Refrigerating Engineer, Carrier Engineering Corp.

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primarily that air conditioning refrigeration requires very large heat capacities, which need be handled only at low temperature heads. Ice making and other low temperature work ordinarily require that the heat be pumped through a much greater temperature range. The analogy to which this might be compared is the use of fans for handling large volumes of air at low pressure differences, as against compressors designed to handle small quantities of air but at relatively high compression ratios.

Air conditioning applications may be divided into two general classes. The first of these is industrial or process conditioning where the refrigeration is employed

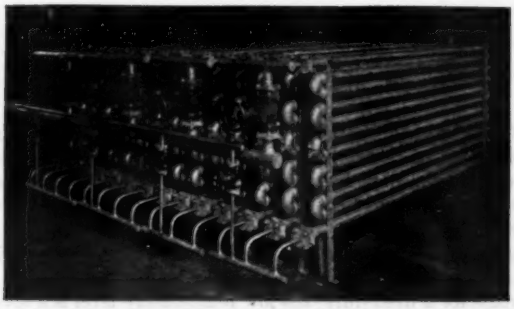

FIG. 1. BAUDELOT COIL ASSEMBLY WITH WATER DISTRIBUTING TROUGHS REMOVED

for the purpose of maintaining low temperatures or relative humidities or both, for the improvement of the product under process of manufacture, or making the manufacturing process independent of climatic conditions. The refrigeration for this phase of air conditioning may be required to produce temperatures anywhere from normal summer conditions, down to zero degrees, or even less. The majority of cases in this class of work, however, will fall in the temperature range requiring cold water or dew-point temperatures from 35 to 60 deg. fahr.

The second major application of refrigeration to air conditioning is that employed in auditoriums or other places of public assemblage. The purpose of this refrigeration is to provide comfort for the patrons of the auditorium. This field of air conditioning is large and has become very important both from the standpoint of its benefits to the public and to the promoters of public enterprise. The range of cold water temperatures or dew points to be maintained for this purpose is fairly narrow and well defined and as employed may be considered to be covered in the range of 40 to 55 deg. fahr., though the best results are generally secured with a dew-point temperature of about 50 deg. fahr.

In either of the applications it is desirable to have equipment which will produce the results efficiently and with the minimum attendance. This efficiency should be easily maintained throughout the life of the equipment at approximately that demonstrable when the equipment is new and first installed. For economy of

operation and satisfactory maintenance of atmospheric conditions, it is also desirable that the equipment permit of automatic regulation of a constant cold-water temperature.

For air conditioning where cold-water temperatures above the freezing point of fresh water are permissible, the most efficient method of heat transfer is by direct spray of the refrigerated water into the air current. This gives a very efficient heat transfer surface so that air may be cooled approximately to the temperature of the cold water leaving the spray chamber. This method of heat transfer combined with an efficient cooling surface for the refrigerated water permits of the main-

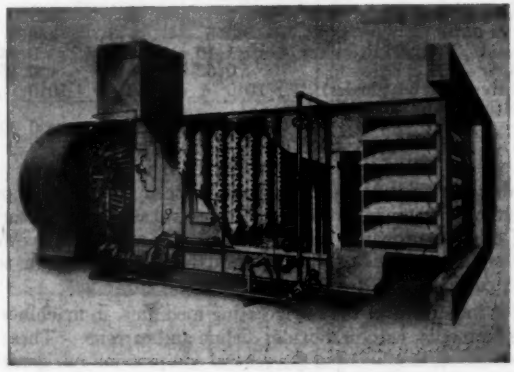

FIG. 2. SPRAY TYPE DEHUMIDIFIER

tenance of dew points very close to the temperature of the refrigerating medium on the low side of the refrigerating system, a condition essential to operating economy.

Refrigerating Mediums

Refrigerating fluids are merely heat-carrying mediums which, during their cycle, absorb heat at a low temperature level, are compressed by a heat pump to a higher temperature, where they are able to discharge their absorbed heat together with that added during the pumping, to the condenser cooling water. The ideal refrigerating medium would be one which could discharge to the condenser all the heat which it is capable of absorbing in the cooler.

All refrigerating mediums, however, carry a certain portion of the heat from the condenser back into the cooler and thus reduce the heat-absorbing capacity of the medium on the low side of the system. This portion constitutes a *floating heat* quantity which requires work in pumping it back to the high temperature plane, but is of no value since it produces no refrigerating effect. The efficiency of the refrigerating medium is thus dependent upon and reduced by this *floating heat* quantity. Fluids which are completely condensable on the high side are more nearly ideal in this respect than dense gases, like dense air for instance. Another

generally reliable index of the relative efficiency of the completely condensable fluids is how far removed their critical temperatures are from their normal operating range. Of course in selecting a medium its characteristics of volume, pressure and chemical activity must be considered in conjunction with the refrigerating mechanism.

TABLE 1. PHYSICAL PROPERTY RELATIONS OF VARIOUS REFRIGERATING MEDIUMS

	Ammonia, NH_3	Carbon Dioxide, CO_2	Carrene, CH_2Cl_2	Dieline, $C_2H_4Cl_2$
Critical temperature ° F.	271	88	421	450
Latent heat (r) at 35°	540.5	97.8	155.6	135
Specific heat liquid (C) at 80° F.	1.10	1.33	0.34	0.27
Specific heat vapor (C_p)	0.52	0.20	0.154	0.162
Ratio r/C_p (relative superheat losses)	1040	489	1010	833
Ratio C/r (relative losses at expansion valve)	0.00203	0.0133	0.00218	0.002

A large number of refrigerating mediums have been investigated, proposed and used to some extent. These might be listed in general as air, water, carbon dioxide, nitrous oxide, ethane, propane, butane, isobutane, ammonia, methyl chloride, ethyl chloride, sulphur dioxide, ether, carbon bisulphide, carbon tetrachloride, dieline, trieline, carrene.

The four most important of the refrigerating mediums, in machines of five tons and larger, are ammonia, carbon dioxide, dieline and carrene. These refrigerants cover all the variations employed in the general compression refrigerating systems.

NOTES FOR TABLES 2 AND 3.

[1] The Progressive Development of Carbon Dioxide Refrigerating Methods, J. C. Goosmann, Refrigerating Engineering, December, 1927.

[2] Data obtained from Bureau of Standards Circular No. 142, on ammonia properties. Power and displacement determinations previously published in detail by W. H. Motz, The Compression Refrigerating Cycle, *Refrigerating Engineering*, Vol. 9, No. 9, March, 1923.

[3] Calculations based on Mollier Diagram compiled by H. J. Macintire in Marks' Handbook, 1924. The theoretical cycle and methods of calculation are further given by J. C. Goosmann, Factors Governing the Liquefaction of Carbon Dioxide, *Refrigerating Engineering*, July, 1927. For the figures given in Tables 2 and 3, the temperature of the refrigerant CO_2 is considered subcooled 10° below the condenser saturation pressure in counterflow double pipe condensers. This is generally done in the best practice.

[4] Internal Pressure, Vapor Pressure and Critical Data of Many Non-associated and Associated Liquids, F. Schuster, *Z. Anorg. Allgem. Chem.*, 1925.

[5] *A.S.R.E.* Circular No. 9, p. 50.

[6] Operating pressures recommended by J. C. Goosmann, Factors Governing the Liquefaction of Carbon Dioxide, *Refrigerating Engineering*, July, 1927.

[7] Horsepower per ton 10° liquid subcooling before expansion valve.

[8] Ten degree liquid subcooling and Multiple Effect operation. Multiple Effect principles and operation described by Gardner T. Voorhees, *Ice and Refrigeration*, 1921, and the book, *Refrigerating Machines, Compression, Absorption*, by G. T. Voorhees.

[9] Effect of low condenser pressures with 10° liquid subcooling.

[10] The actual brake horsepowers required in the above cycles are about 50% greater than the theoretical, except for CO_2 in Column 8. Under this condition of operation, a slightly greater per cent increase for the actual above the theoretical horsepower may be expected, due to the fact that the Multiple Effect equipment cannot effect its economies without some losses.

For further comparisons of refrigerating fluids see Comparison of Thermodynamic Characteristics of Various Refrigerating Fluids, by W. H. Carrier and R. W. Waterfill, *Refrigerating Engineering*, June, 1924.

TABLE 2.* THEORETICAL HORSEPOWER ONE TON OF REFRIGERATION
SUCTION TEMPERATURE 20° F.—CONDENSER SATURATION TEMP. VARIABLE

Sat. Temp. ° F. Corresponding to Condenser Pressure	Ammonia (NH_3)[2] Suct. Press., 33.5 Lb./Sq. In. (ga)			(CO_2)[3] Suction Pressure, 407.3 Lb./Sq. In. (ga)									(CH_3Cl)[4] Suct. Press., 25 Inches Hg. Vacuum			(C_2H_5Cl)[5] Suct. Pressure, 27.3 Inches Hg. Vacuum		
	Cond. Press., Lb./Sq. In. (ga)	Horsepower	% Tons Cap. (Const. Net Displacement)	Cond. Press., Lb./Sq. In. (ga)	Horsepower (Supercharged)	% Tons Cap. (Const. Net Displacement)	Horsepower (Supercbgd.-Mult. Effect)	% Tons Cap. (Const. Net Displacement)	Cond. Press., Lb./Sq. In. (ga)	Horsepower (Normal Charge)	% Tons Cap. (Const. Net Displacement)	Cond. Vacuum, Inches Hg.	Horsepower	% Tons Cap. (Const. Net Displacement)	Cond. Vacuum, Inches Hg.	Horsepower	% Tons Cap. (Const. Net Displacement)
1	2	3	4	5[8]	6[7]	7	8[8]	9	10[9]	11[9]	12[9]	13	14	15	16	17	18
80	138.3	0.67	100	1025	0.91	100	0.71	100	945	0.85	100	12	0.66	100	17.6	0.65	100
85	151.7	0.73	98.8	1110	1.05	96	0.80	98.7	1025	1.00	95	10	0.72	98.8	16.2	0.71	98.8
90	165.9	0.80	97.6	1210	1.22	92	0.89	97.4	1085	1.16	91	7.8	0.78	97.6	14.5	0.77	97.6
95	181.1	0.87	96.3	1300	1.39	88	0.99	96.2	1120	1.35	84	5.5	0.84	96.3	12.8	0.83	96.3
100	197.2	0.93	95.0	1400	1.58	84	1.09	95.0	1135	1.58	69	2.8	0.90	95.0	10.8	0.89	95.0

TABLE 3.* THEORETICAL HORSEPOWER ONE TON OF REFRIGERATION
SUCTION TEMPERATURE 35° F.—CONDENSER SATURATION TEMP. VARIABLE

	(NH_3)[2] Suct. Press., 51.6 Lb./Sq. In. (ga)			(CO_2)[3] Suction Pressure, 511.7 Lb./Sq. In. (ga)								(CH_3Cl)[4] Suct. Press., 24 Inches Hg. Vacuum			(C_2H_5Cl)[5] Suct. Press., 26 Inches Hg. Vacuum		
1	2	3	4	5[8]	6[7]	7	8[8]	9	10[9]	11[9]	12[9]	13	14	15	16	17	18
80	138.3	0.48	100	1025	0.71	100	0.52	100	945	0.64	100	12	0.47	100	17.6	0.46	100
85	151.7	0.53	98.9	1110	0.83	95	0.61	98	1025	0.75	95	10	0.52	98.9	16.2	0.51	98.9
90	165.9	0.60	97.8	1210	0.98	90	0.70	96.2	1085	0.86	90	7.8	0.58	97.8	14.5	0.57	97.8
95	181.1	0.66	96.7	1300	1.14	85	0.78	94.5	1120	0.99	83	5.5	0.64	96.7	12.8	0.63	96.7
100	197.2	0.73	95.5	1400	1.30	80.5	0.89	93.0	1135	1.22	69	2.8	0.70	95.5	10.8	0.69	95.5

* For notes see p. 506.

All of the other refrigerating mediums have been employed in efforts to overcome some of the minor disadvantages which have appeared in previously employed substances, or to meet special applications. These other refrigerants in general, however, have introduced, in the main, disadvantages far in excess of the advantages.

Ammonia is a very efficient and workable fluid usually employed in piston type or positive displacement compression machines, though it has been used to some extent in centrifugal machines of very large capacity. The working pressure range for air conditioning is approximately 30 to 50 lb. gage on the low side, and 180 to 225 lb. gage on the high side.

Carbon dioxide is the only medium employed in piston compression systems,

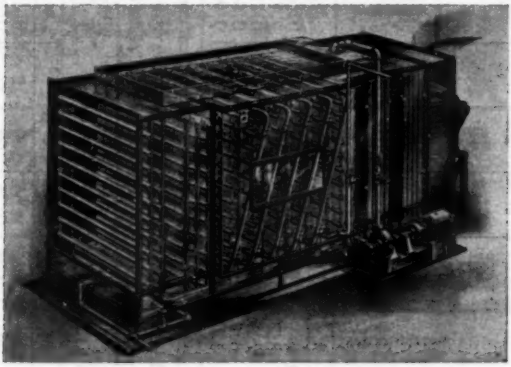

FIG. 3. WETTED BUNKER COIL DEHUMIDIFIER

which has sufficiently marked safety advantages over ammonia to warrant its substitution, where safety is the chief concern. As compared to the latter, however, it has some disadvantage in the basic efficiency of its thermodynamic cycle owing primarily to its low critical temperature of 88 deg. fahr. Its working pressures range from 400 to 1400 lb. per square inch gage.

Dieline and carrene are only applicable in non-positive types of compression systems. Both of these refrigerants are water-white liquids at normal atmospheric conditions, and may be handled freely in open containers very much as water is handled. The working pressures on both sides of the system are below atmospheric; that is, the entire cycle of the fluid is completed under vacuum. Working pressures are dieline 27 in. Hg. to 10 in. Hg. vacuum and carrene 26 in. Hg. to 3 in. Hg. vacuum.

Dieline is slightly combustible when ignited with a flame, but the products of combustion will generally blanket and extinguish the flame. Carrene, which may be interchangeably used in the same refrigerating system, is non-combustible.

Some very interesting, though general, deductions regarding the behavior of vapor refrigerating mediums in compression machines can be obtained by comparing their physical property relations, as in Table 1. The nearness of the critical temperature to the operating range may be taken as an index of what losses might be expected in the working cycle of the fluid at the expansion valve. A further ndication of the losses at the expansion valve is given by the ratio C/r, or specific heat of liquid divided by the latent heat. The ratio of latent heat to specific heat of the vapor, or r/C_p, indicates the relative magnitudes of the cycle losses due to superheating during compression.

It will be noted that the relations for ammonia, carrene and dieline are fairly close in every respect, except critical temperatures. Carbon dioxide has quite

FIG. 4. POSITIVE COMPRESSION SYSTEM WITH D. P. CONDENSERS

a low critical temperature and it would thus be expected that relatively high losses would result at the expansion valve. This is further borne out by the C/r relation, which indicates that this loss is about six times that of the other fluids. Recent improvements in equipment have reduced this loss materially, and these improvements contribute to the results for CO_2 in Tables 2 and 3. On the superheat side of the cycle, however, the loss is fairly low, being approximately 50 per cent of that for the other mediums. These relations are only approximate, being given here to illustrate the general vapor laws.

Tables 2 and 3 give the expected theoretical horsepower requirements per ton of refrigerating capacity for the two saturation suction conditions of 20 and 35 deg. fahr. The table is based on varying saturation condenser temperatures from 80 to 100 deg. fahr. The corresponding working pressures for the different fluids are given, together with the theoretical horsepower requirements and per cent capacity, based on constant displacement. One hundred per cent capacity is taken at the low condenser saturation temperature condition of 80 deg. fahr. The capacity reduction is due directly to the decrease in refrigerating effect per cubic foot handled with the increasing condenser temperatures. The horsepower is that per ton

throughout. The method of calculation is standard for the adiabatic cycles and the results are derived from the most authentic physical properties data at present obtainable.

Carbon dioxide, due to the fact that its critical temperature is close to the working pressure, presents a very unique cycle. In view of its many interesting possibilities and variations the CO_2 cycle is given more in detail. Unlike the other refrigerating mediums, the condenser pressure in the carbon dioxide cycle is not determined by the condensation temperature. For this reason, J. C. Goosmann[4] recommends certain pressure conditions for super-charging the condenser at differ-

FIG. 5. CENTRIFUGAL REFRIGERATION INSTALLATION

ent temperatures. These super-charge pressures have been used in Column 5 and give the power and capacity results of Columns 6, 7, 8 and 9. It is desirable to operate at approximately these pressure conditions as they give the best performance of power and maintained capacity for the system. An automatic valve[1] for maintaining the operation of the CO_2 machine on these suggested temperature pressure relations has been described by Mr. Goosmann and should prove quite valuable in CO_2 plant operation.

With double pipe counterflow condensers it is possible to subcool the refrigerant below the saturation condenser pressure. Column 6 is based on subcooling 10

[1,4] See page 506.

deg. fahr. below the saturation pressure and probably represents the theoretical power requirements of the average installation.

Further gains on this cycle can be secured by operating with a multiple effect system. This was described several years ago by Gardner T. Voorhees.[8] The theoretical results obtainable from this method of operation are given in Column 8 and compare quite favorably with those for ammonia and other refrigerants, showing what can be done with a medium like CO_2, when properly installed and operated.

The decrease in capacity due to high condenser pressures, as given in Column 9,

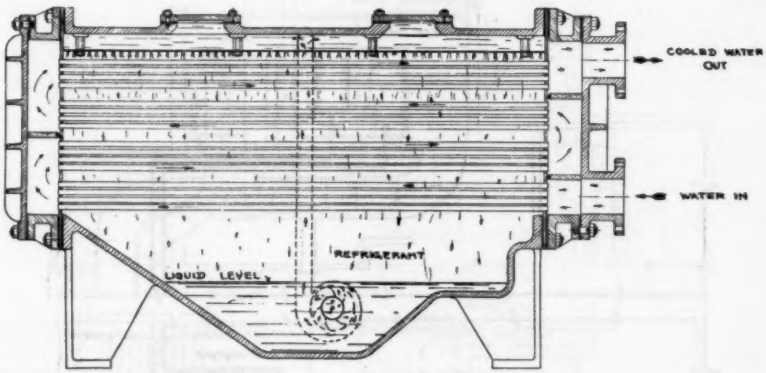

FIG. 6. CONSTRUCTION OF WATER COOLER IN CENTRIFUGAL REFRIGERATING SYSTEM

is quite small. Of course for this method of operation there is the efficiency of the multiple effect devices to be considered in addition to the compression efficiency.

Columns 10, 11 and 12 indicate what the performance of the system might be without proper condenser pressures, emphasizing the advantages of correct operation. The horse-power figures of Column 11 compare favorably with those of Column 6, the reason for this being in the 10 deg. subcooling of the liquid before the expansion valve. Mr. Goosmann, of course, has based his supercharge pressures on a simple cycle without liquid subcooling, in which case the advantages of supercharging would be more apparent.

Refrigerating Mechanisms

For the conversion of energy in the various forms of useful work, machinery has been evolved and carried through various stages of development and improvement, with the object of increasing its efficiency, simplicity, dependability and automatic performance. History shows that, in general, piston type engines, pumps, compressors, etc., were the first developed. Later centrifugal, or free rotating units were devised and soon established themselves. These are the steam turbine,

[8] See page 506.

centrifugal pump, centrifugal fan, centrifugal blower and centrifugal compressor, as well as electric motor. The piston type machine and the centrifugal, or free rotating type machine each, in general, have their preferred field of operation. As a general rule, the centrifugal unit is best adapted for fairly large sizes and relatively low pressures, while the positive piston type machine finds its field of usefulness in smaller capacities and high operating heads, *i. e.*, ventilating fans contrasted to compressed air garage pumps.

In the present state of development it would seem that centrifugal machines are commercially applicable only to the larger capacities, and certainly not below

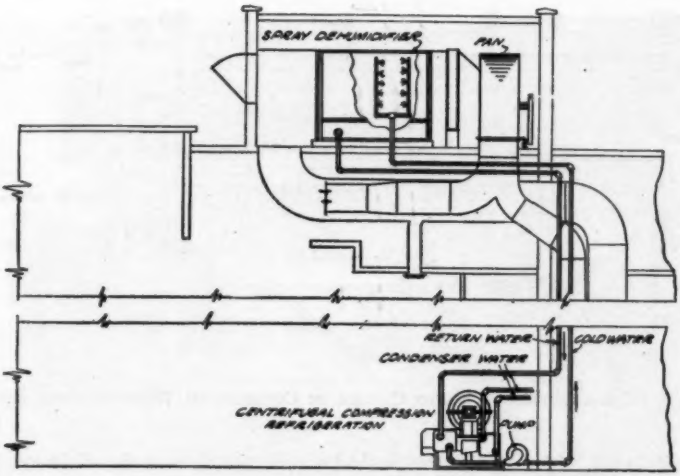

FIG. 7. DEHUMIDIFYING SYSTEM—CENTRIFUGAL REFRIGERATION

about 50 tons in a single unit. For all smaller capacities, positive compression machines have inherent advantages in first cost and, to some extent, in operation. In the smaller capacities, centrifugal machines must either increase in speed or else operate at reduced efficiency. In the small positive compression machines an increase in speed is desirable and there is but little disadvantage in efficiency in the smaller sizes. There are many other considerations determining the type of compression to be employed, as, for example, whether a steam engine or steam turbine drive is preferred in steam driven units. It is obvious that a centrifugal type of unit is not adapted for steam engine drive and conversely positive compression is not so well adapted for steam turbine drive.

While the majority of refrigeration installations for air conditioning are of the compression type, there are still employed a number of ammonia absorption units. This is one of the oldest methods of refrigeration and has found favor where large quantities of waste heat in the form of low pressure steam are available.

Absorption systems, however, have been little used in air conditioning work as they are best adapted to low temperatures. Increased back pressures occurring in air conditioning work do not give the advantage in this type of equipment that they offer in the positive compression machines, and the cost of the absorption system in general is more than for compression systems. It is quite possible, however, that for small units the absorption system may find increased favor as it has possibilities of automatic operation and freedom from moving parts that cannot be obtained in the compression system. It is particularly well adapted

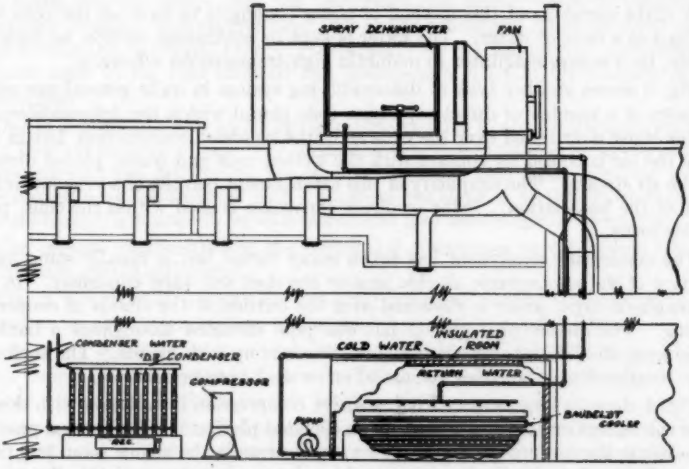

FIG. 8. DEHUMIDIFYING SYSTEM—PISTON COMPRESSION REFRIGERATION

where low pressure steam is continually available, or gas may be used as a fuel for operation.

In addition to the older type of ammonia absorption machines, there are two new types of absorption machines coming into use. One is the hydrogen filled machine now in use only in gas-fired household refrigerating machines, and the other is an absorption machine using solid absorbents, such as silica gel. Both of these systems have possibilities for further development. There is also a system being developed which is gas-fired but which is not an absorption machine. It is really a compression machine using mercury vapor as the ejector medium. This machine uses water vapor as the refrigerating medium. It is quite possible that one or more of these systems will eventually be developed for the cooling and air conditioning of our homes in summer, and for other places where only relatively small quantities of refrigeration are required.

The piston compression machines were first employed in the latter half of the nineteenth century. They are generally connected to baudelot coils or bunker coils on the low side, for air conditioning. The baudelot coil construction shown

in Fig. 1 consists of a series of pipes made up to form a vertical coil or stand. Several of these stands are placed together to form a bank, the number of stands required depending on the capacity of the installation. These coils are placed in an insulated room with a water tank at the bottom. The water to be cooled is distributed by drip troughs, and runs down over the coils. The refrigerant is expanded or vaporized within the coils, thus absorbing the heat from the water flowing on the outside. The water, when cooled, is then pumped to a dehumidifier, similar to Fig. 2, through which the air to be cooled is passed. The water is then returned by gravity to the baudelot tank and recooled.

A slight variation of this method of water cooling is to have all the coils submerged in a tank of water. The water is kept in continuous motion at high velocity, by a separate agitator to maintain high transmission efficiency.

Fig. 3 shows another type of dehumidifying system in quite general use which consists of a number of direct expansion coils placed within the dehumidifier, the water being distributed over the coils as in the baudelot construction, but in this case the air is cooled by contact with the wetted coils and water, placed directly in the air stream. The simplicity of this arrangement permits of a very low initial cost of the installation. Brine or direct expansion is used within the coils, preferably brine.

The condensing equipment has taken many forms, but is usually some modification of the atmospheric, double pipe or the shell and tube condenser. In the atmospheric type, water is showered over the outside of the stands of connected piping. The double pipe system has one pipe threaded throughout a bank of large pipe, the joints being either welded or made up with glands. The shell and tube condenser may be either horizontal or vertical, open or enclosed.

Fig. 4 shows a large steam drive, positive compression installation with double pipe condensers arranged in a bank on an elevated platform. The general practice is to locate the compressor and drive on foundations in the engine room and place the cooling and condensing equipment wherever convenient, connecting these units with pipe lines for the circulation of the refrigerating liquid and vapor. Here the compression and condensing units are in the engine room and the baudelot, or cooler surfaces, located elsewhere.

The centrifugal compression machine is of comparatively recent origin, having made its first commercial appearance in 1923 in connection with air conditioning in the chocolate dipping room of a large candy factory in the United States.

All the units of this system are erected in a compact assembly. The compressor and drive are mounted directly on the shell and tube type cooler and condenser, which serve as a subbase. The assembly is generally set directly on the floor. The compressor may be direct connected to steam turbines, which will run at their normal speeds. Turbines may be thus employed for all steam pressures, even as low as 2-lb. gage. High speed electric motors are often used to drive the compressor direct connected, also variable speed motors connected through step-up gears.

The characteristics of a centrifugal compressor make it adaptable to automatic regulation of the cold water temperature, regardless of the load. The general method of doing this is by controlling the flow of cooling water to the condenser. This means that the consumption of condenser water is always governed by the

amount of refrigeration load, thus insuring the economical use of condenser water. Further regulation may be had by variable speed, which reduces power required at reduced loads. This method of regulation is particularly desirable where material economy cannot be effected by condenser water reduction. This is the case for very cheap or fixed condenser water costs, as when water is pumped from rivers or in cooling tower circuits.

In the centrifugal system, the fresh spray water for the dehumidifier may be cooled direct in a shell and tube cooler without danger of water freezing within the tubes, for the reason that the centrifugal compressor tends to maintain a relatively constant temperature head just as the centrifugal pump tends to maintain a constant hydraulic head. The capacity of the compressor automatically adjusts itself to the load imposed and maintains a constant temperature of the cooled water.

One of the peculiarities of the refrigerants available in the centrifugal system is that they are solvents of oil. The cooler and condenser surfaces, being continually showered with the refrigerant, are thus washed and kept clean, insuring a high maintained heat transmission rate. However, as there is no internal lubrication of a centrifugal compressor, no oil is introduced into the refrigerant passages.

The general construction of the centrifugal compressor is very much like the multi-stage centrifugal pump.

Fig. 5 is a typical installation showing the water piping connections to the closed water circulation systems of the condenser and cold water cooler.

Fig. 6 is a standard shell and tube cooler, showing the method of heat transfer from the refrigerant to the cold water and the general water and refrigerant circulations. A shell and tube condenser functions in the same manner.

A completely centrifugal dehumidifying air conditioning installation is shown in Fig. 7, and a similar arrangement for a piston compression type installation is shown in Fig. 8.

DISCUSSION

L. A. HARDING: This is a very interesting paper and it is one that we needed. We have had very little data presented on refrigeration and I think many members would like to know more about refrigeration as applied to air conditioning. One thing that I noticed in the paper is that the horsepowers stated are based on the theoretical horsepower per ton of refrigeration and shows that the four refrigerating media mentioned give about the same results theoretically.

Although I didn't have an opportunity to figure it out for the temperature ranges stated, I imagine that air would show up as satisfactorily. The theoretical horsepower per ton does not give a true picture of the proposition by any means. I am not satisfied that the centrifugal type compressor employing the media stated would favorably compare with the reciprocating compressor using ammonia based on brake horsepower per ton of refrigeration. I would like very much to see added to this paper a comparison of actual tests. There are available for the ammonia machine the York tests on the single and double acting ammonia compressors

made a number of years ago, and there are also available some tests on CO_2 machines.

THORNTON LEWIS: There is one point in connection with the comparison of centrifugal and reciprocating compressors that is made in the paper, but not emphasized and which I think is quite significant and should be stressed. With the centrifugal compressor it is not necessary to lubricate the internal surfaces; therefore, in going through the pipes that carry the refrigerant there is no danger of an oil or other lubricant being deposited. It seems to me that this alone is a very great advantage and I certainly hope that as the thoughts of our scientists progress, it may be possible to find a new refrigerant which will allow a small compressor to be perfected which will operate within reasonable speed limits.

O. W. ARMSPACH: I want to concur with Professor Harding. He has taken most of the wind out of my sails with his discussion of the table on theoretical horsepowers. I regret that actual horsepowers were not given in connection with these theoretical data, as the actual horsepowers may be different than the tendency shown by the theoretical horsepowers.

Referring to Table 2, I believe that additional data for saturation temperature below 80 deg. would be of value on account of the comparatively low critical temperature of carbon dioxide.

In the author's discussion of the baudelot cooler and dehumidifier combined, he states that brine is to be preferred to direct expansion within the cooling coils. The use of brine, of course, requires at least 10 deg. lower gas temperatures and lower suction pressures, which means lower efficiencies, smaller capacities for the same size of equipment and increased horsepower per ton. I know of no reason why brine should be used in any air cooling installation.

W. H. CARRIER: There is one other question I would like to speak about. In air conditioning work, all your big loads where your maximum power is taken is carried during the summer months. It is seldom you will get water lower than 65 deg. You cannot obtain the conditions given, 80 deg. saturation temperature and 70 deg. liquid temperature, with water higher than 65 deg. entering the condenser.

With carbon dioxide, if water enters the condenser at 75 deg. with counter-flow effect and leaves at 80 deg. there will be little or no gain in using more water.

The point brought out with reference to the efficiencies is quite important, but it is very difficult to give in any table either test or practical efficiencies owing to the wide variation of efficiencies of types of compressors used, even with positive compression and efficiencies in practice rather than laboratory efficiencies which are apt to be still farther off. Practical efficiencies should be taken after two or three years of operation with normal conditions. These will differ in many cases considerably from initial conditions.

Centrifugal pumps give good efficiencies. Today at our water works we do not use in the newer plants the positive piston type to any extent. They are centrifugal type and they are centrifugal type because of operating economy, not test block economy, although they compare very well. The centrifugal pump will give efficiencies in larger sizes as high as 80, and in the smaller 65 to 75. The same

thing is true of centrifugal compressors when designed along the same scientific line. The General Electric Co. are making centrifugal air compressors that give efficiencies based on adiabatic compression above 75% based on the actual working condition. Taking into account the heating up of the medium the actual, or mechanical efficiency, goes slightly above 80 per cent.

The adiabatic efficiency of any compressor is not as great as it would be if it were not for the temperature rise of the gas in the process of compression, and that is a reason for lower efficiencies of any type of compressor compared with what we would expect in a water pump. I think we may say that the centrifugal machine has advantages that will be exploited by all manufacturers for the larger sizes in a relatively short time.

R. W. WATERFILL: It is theoretically possible to obtain a very good efficiency in a refrigerating cycle using air. To produce such a cycle with air, however, requires many complications not necessary with a condensable fluid. The air cycle must be staged cooled during compression, refrigerative during expansion and completely regenerative on expansion from the high to the low pressure for any reasonable efficiency. This would produce a ratio of net refrigerating effect to net power consumed, comparable with the cycles using condensable vapors. The actual results, however, are limited by the number of stages practicable, and still further reduced by the efficiency of the regenerative mechanism which is additional to the usual compression mechanism.

The actual horsepowers are very difficult to give and would lead to no end of controversy. Over-all efficiencies of refrigerating systems vary greatly with methods of operation and with the condition of the equipment. Theoretical adiabatic powers are established by physical laws and not by manufacturers or operators. These laws determine the standards toward which practice must strive.

The chemical formula for Carrene is given in the table.

I believe the question regarding the 80 deg. minimum saturation temperature given in the tables has been answered. The greatest refrigerating load for dehumidifying and air cooling occurs during the summer months when condenser cooling water is hottest. A few cities near the Great Lakes have city water in summer at a temperature of 65 to 72 deg. fahr. A few cities are supplied with cold well water, others are not so fortunate. A 15 to 20 deg. condenser water temperature rise is usually most economical for purchased water and refrigerants like ammonia.

For many air conditioning applications refrigeration would hardly be required when condenser saturation temperatures less than 80 deg. were obtainable.

In regard to the statement on page 514 that brine would be preferred within these coils, I had in mind the avoidance of any leakage of refrigerant, which might occur from the coils, getting into the circulating air.

No. 815

AIR LEAKAGE THROUGH A PIVOTED METAL WINDOW

By F. C. Houghten[1] and M. E. O'Connell[2]
Pittsburgh, Pa.

MEMBERS

DURING the fall of 1927 an opportunity presented itself for the Research Laboratory of the American Society of Heating and Ventilating Engineers to make a study of air leakage through a pivoted window in the Grand Central Palace Bldg., Lexington Ave. and 46th St., New York City, during the Power Show. The set-up and the operation of the test served as an exhibit and demonstration of the work of the Laboratory.

Description of Building

The Grand Central Palace, Fig. 1, is a 12-story building, facing Lexington Ave. from 46th St. to 47th St., and is 270 ft. deep. The study was made in a window facing west, about 25 ft. from the north corner of the 4th floor. The nearest obstruction to free wind movement west of this window was at a distance of approximately 52 ft. 6 in., so that the wind had a fairly clear sweep from the northwest through 47th St., and this vacant space.

The first four floors of the building were used as exhibition space in the Power Show and were interconnected by large open stairways. None of the floors were subdivided into rooms. There was little tendency, therefore, for the air leaking in through the windward windows to build up pressure within the room—for the reason that it could easily get out of the building around the large number of windows and doors on the opposite side.

The window studied, Fig. 2, was of the hollow metal vertically pivoted type. Each window unit was divided into four sections by the metal frame which was flush with the plastered wall. The perimeter tested was 20 ft. 4 in. The joint between the plaster and the frame was tight and appeared to offer little opportunity for frame leakage. The window sash was not in good shape and fitted very loosely into the frame without weatherstripping.

Test Procedure

The apparatus used and the method of conducting tests was identical with that

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Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, West Baden, Ind., June, 1928.

used in the Southwestern Bell Telephone Bldg., and described in an earlier Laboratory report.[3] The collecting hood, the meter for measuring the leakage, the control valves and the exhaust blower were connected to the window as shown in Fig. 3. This method of application differs from that used in the investigation just referred to only in that tie-rods were used for drawing the hood up to the wall around the window instead of the brace and jack-screw used in the earlier study.

FIG. 1. GRAND CENTRAL PALACE BUILDING, LEXINGTON AVE. AT 46TH ST., NEW YORK, N. Y.

Fig. 4 is a photograph of the test set-up. The window is h dden from view by posters and signs.

The test manipulation was the same as that referred to in the earlier report and will not be repeated here. Tests were made with both natural and artificial wind pressures. When the leakage resulting from natural wind pressures was measured, the air leaking through the window into the hood and the pressure drop through the window were measured simultaneously for the wind prevailing at that time. The leakage for artificial wind pressures was measured by artificially producing a pressure drop through the window by exhausting air from the hood.

[3] Air Leakage Studies on Metal Windows in a Modern Office Building, by F. C. Houghten and M. E. O'Connell, TRANSACTIONS, 1928, OF AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, p. 321.

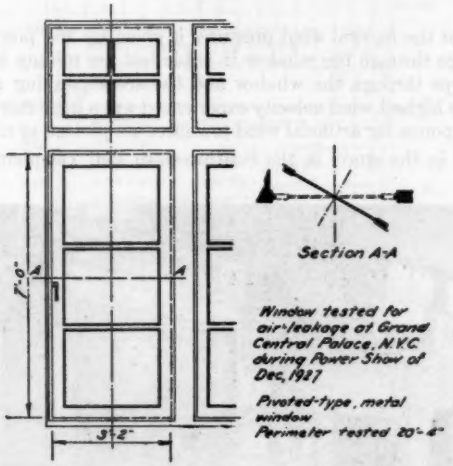

FIG. 2. PIVOTED METAL WINDOW

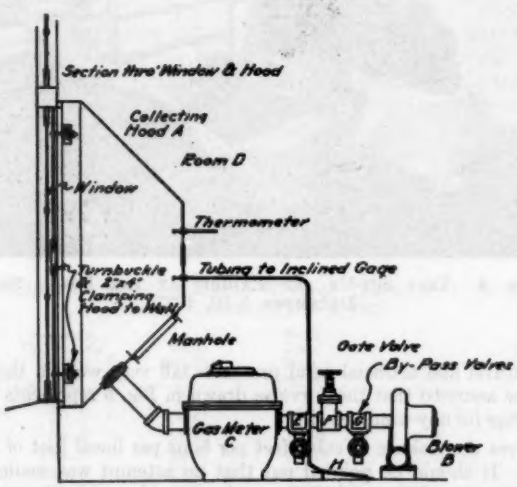

FIG. 3. APPLICATION OF AIR LEAKAGE APPARATUS TO WINDOW

Test Results

The leakage for the natural wind pressures is given by the points x in Fig. 5, in which the leakage through the window in cubic feet per minute is plotted against the pressure drops through the window and the accompanying velocity. It will be noted that the highest wind velocity experienced was a little more than 10 mi. per hour. The test points for artificial wind pressures are plotted as circles.

As was found in the study in the Southwestern Bell Telephone Bldg., the test

FIG. 4. TEST SET-UP AND EXHIBIT AT THE POWER SHOW, DECEMBER 5–10, 1927

points for natural and artificial wind pressures fall very well on the same curve, and it may be assumed that the curve as drawn in Fig. 5 represents the true condition of leakage for any wind velocity.

Table 1 gives the leakage in cubic feet per hour per lineal foot of crack around the window. It should be pointed out that no attempt was made to eliminate leakage between the plaster and frame on the one side and bottom of the window covered by the hood. As previously stated, however, the joint between the plaster

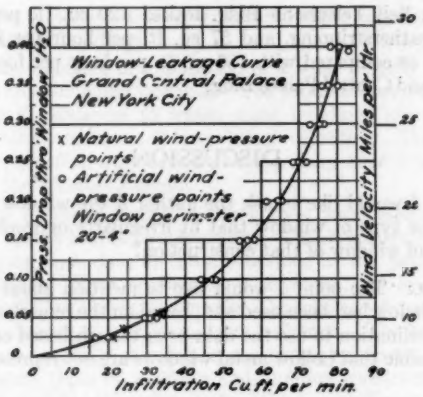

FIG. 5. RELATION OF AIR LEAKAGE TO WIND PRESSURES AND VELOCITY

and the frame appeared to be well sealed, and one would not expect a very large error due to frame leakage. The table also gives leakage for the entire area of the window studied; that heat loss in B.t.u. per hour required to heat the air leaking in from 0 to 70 deg. fahr. and the square feet of radiation required to supply this heat loss.

The last column of the table gives the cost of installing radiation to take care of the heat loss, based upon $2 per sq. ft. installed. This would indicate that the application of weatherstripping and the resultant decrease in the amount of radiation installed would give a considerably lower first cost for the completed building—to say nothing of the saving in heat thereafter.

It is of interest to compare the leakage through this window, which was noticeably loose-fitting, with the leakage through the windows of the Southwestern Bell Telephone Bldg. as given in the report previously referred to. If this comparison is made on the basis of a 20-mile wind velocity, the unweather-stripped window in

TABLE 1. INFILTRATION THROUGH METAL WINDOW TESTED AT N. Y. POWER SHOW, GRAND CENTRAL PALACE, 1927

Wind Velocity, Miles per Hr.	Leakage, Cu. Ft. per Hr. per Ft. of Perimeter	Total Cu. Ft. per Hr.	Heat Loss, B.t.u. per Hr. 0–70° F.	Sq. Ft. Radiation	Cost of Radiation at $2.00 per Sq. Ft. Installed
5	29.5	600	756	3.2	$ 6.40
10	88.5	1800	2268	9.5	19.00
15	144.5	2940	3710	15.5	31.00
20	186.0	3780	4767	19.9	39.80
25	221.5	4500	5677	23.7	47.40
30	242.0	4920	6202	25.9	51.80

the Southwestern Bell Telephone Bldg. leaked 120 cu. ft. per hour per foot of crack without weatherstripping, and 57 cu. ft. per hour per foot of crack with weatherstripping, as compared with 186 cu. ft per hour per foot of crack for the window in the Grand Central Palace Bldg.

DISCUSSION

E. C. EVANS: I would like to ask the author if the window he had under discussion was a poor type of window that fit irregularly or would it be considered as a general type of window of that construction?

W. C. RANDALL: The point I would like to mention about this paper is that apparently one window had been used and, based on the remarks of the last speaker there will be an inclination to use the data even though based on but one window. It is perfectly possible that hollow metal windows are not represented by this chart adequately.

The other point is that the author has transferred the infiltration into square feet of radiation.

Now, the data which he has shown would seem to indicate that he did not get the drop in pressure of greater than the equivalent of about 10 miles wind velocity, whereas the wind was actually blowing more than that, and the building in a more or less exposed position.

It seems to me there has to be a better known relation between the wind velocity at the recording station and the drop in pressure between the outside and inside faces of the window before we can interpret into square feet of radiation.

J. E. EMSWILER: Mr. Houghten has in common with the usual practice on the infiltration test expressed the quantities here as heat loss in B.t.u.'s per hour and has referred to the 70 deg. basis. We, of course, all understand that to be a figure upon which is based the calculation of an extra portion of radiation necessary to take care of that infiltration.

The point I want to make, however, is that this heat loss item may possibly be misinterpreted by some and interpreted to mean an actual loss in B.t.u.'s that is existing at all times.

Now, of course, infiltration is taking place only during a relatively small percentage of the total year or total heating season, and we ought to be particularly careful to make the point that if infiltration is cut in half, for example, it isn't going to mean any extensive heat loss or heat saving, after all.

F. C. HOUGHTEN: Mr. Evans asked concerning the condition of the window on which the data reported was collected. As pointed out in the paper, the window is of the vertical pivoted type and in rather poor condition as regards tightness of fit. I believe one would expect a window in a ten-year old building to be in a rather poor condition, but we are not in a position to say whether or not the window tested is typical of those found in buildings of similar age.

As pointed out by Mr. Randall, the data were collected on only one window and the importance of the findings should be discounted due to this fact. How-

ever, they should be of some value in indicating what may be expected under existing conditions in old buildings.

There is always the question of application of a wind velocity reported by the Weather Bureau, to any particular building. The wind as reported by the Weather Bureau is probably a maximum to which some buildings are subjected, while most buildings are subjected to much lower wind velocities. The best that can be done in making a practical application at the present time is to accept the velocities reported by the Weather Bureau.

As pointed out by Professor Emswiler, the highest wind velocities are perhaps never accompanied by the lowest temperatures. This is a question of paramount importance in applying such data as those contained in the paper, to determine heat loss from buildings. Such application is, however, not so much a function of this paper as it is of THE GUIDE Publication Committee who are wrestling with it in developing the chapter of heat losses from buildings. The heat loss values as given in the paper are primarily of value, in comparing relatively, the heat loss by infiltration for different types of windows and building construction. In recommending methods of applying these data in THE GUIDE, it will probably be desirable to take some percentage of the values actually found in the test, as has been done in developing other tables for air leakage from laboratory data.

In the discussion it was brought out that maximum wind velocities are met with over a very small proportion of the heating season and that the extra radiation necessary on a cold windy day to take care of infiltration, will not reflect a relative increase in total heating requirement for the season. This is, of course, quite true, but nevertheless, sufficient radiation must be installed to meet the worst condition, and the first cost of installing such radiation can be eliminated by cutting out the air leakage, In this connection, it should be pointed out that in the case of any window giving an excessive leakage, the first cost of installing a better window or leakage retarding device, is more than off-set by the reduction in cost of radiation.

No. 816

THE WEATHERTIGHTNESS OF ROLLED SECTION STEEL WINDOWS

By J. E. Emswiler,[1] and W. C. Randall[2]

MEMBERS

Information is presented in this paper on the weathertightness of rolled section steel windows, as a contribution to the general subject of infiltration, and is based upon laboratory tests and field surveys of various types of windows of this class. Results show that steel windows manufactured of solid rolled sections are, on the average, more weathertight than wood windows, notwithstanding a rather widespread opinion to the contrary. Former papers presented before the Society on the subject of infiltration have been based chiefly upon tests of double hung wood and metal windows. (See bibliography at end of this paper.)

Factors Influencing the Weathertightness of Windows

Infiltration is dependent upon two things, *viz.*, the leakage opening, and the pressure difference that causes flow.

The leakage opening is determined by the length and width of crack between the fixed and movable contact surfaces. It is something that depends upon the type, design, manufacture and installation of the window.

The difference in pressure between the inside and outside faces of a window is a function of the aerodynamic forces that prevail in and about the building.

Outside of any frame crack that may exist, the length of the leakage opening is usually the total perimeter of the movable portions of the window. The double hung window always presents the same length of crack for leakage, *viz.*, approximately twice the height of the window plus three times the width. In the rolled section type of steel window with pivoted or swinging ventilators, the ratio of ventilating area to window area is adaptable to the needs of the installation, and the crack length varies with the ventilation area provided. For a ventilating area equal to 50 per cent of the window area, the crack perimeter of a steel window will vary between 60 per cent and 90 per cent of the crack perimeter for double hung windows.

The width of crack is dependent upon the type and construction of the window and care in installation. The sidewall factory type, for instance, will be expected

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Presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, West Baden, Ind., June, 1928.

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to show a larger leakage crack than the more heavily constructed casement section projected window, or the more carefully designed and manufactured casement section residential type of window.

Frames and ventilators distorted in shipment and handling can and should be readjusted into contact during installation. Examples of steel windows have been found in which chunks of mortar and plaster had been allowed to remain and harden on the contact surfaces and were often the cause of excessive crack widths. Cases have been observed of non-functioning latches and locks for clamping ventilators in the closed position that indicate further carelessness in installation. Better

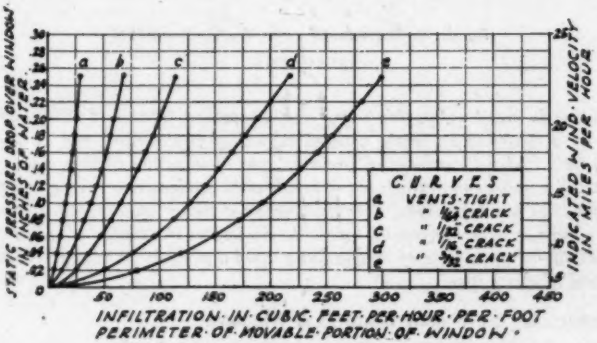

FIG. 1. RESIDENTIAL CASEMENT STEEL WINDOWS

results usually can be expected if the manufacturer is responsible for the installation.

Nomenclature of Solid Section Steel Windows

In explanation of the terms used to describe the types of steel windows, in Tables 1 and 2 and in the figures containing the curves the following brief definitions are given:

The heavy section casement is a window manufactured of the so-called heavy casement sections. The leaves are hinged at the side and usually swing out.

Heavy casement section projected is a window manufactured of the same kind of sections as the heavy section casement window. The ventilators swing out or in, and are balanced on side arms that cause the ventilators to stay put at any degree of opening.

The residential casement window is of the same design, and is manufactured of the same shaped sections as those used in heavy section casement, but lighter in weight, and the swinging leaves cannot be built so large.

The industrial pivoted window is generally employed in industrial buildings. The ventilators are pivoted, usually horizontally at the center or slightly above, the lower part of the ventilator swinging out and the upper part swinging in.

Commercial projected is a type of window manufactured of the same sections as are industrial pivoted windows, but the ventilators swing in or out and are balanced on side arms as do the ventilators in heavy casement section projected windows.

Architectural projected is a type of window usually manufactured of the same sections as commercial projected windows, except that the outside framing member is usually heavier, and there are refinements in the weathering and hardware, with the result that this window is usually used in the semi-monumental type of building such as schools. The ventilators swing in or out and are balanced on side arms.

Infiltration Curves for Rolled Section Steel Windows

The curves of Figs. 1, 2, 3, 4 and 6 show the results of laboratory tests to determine

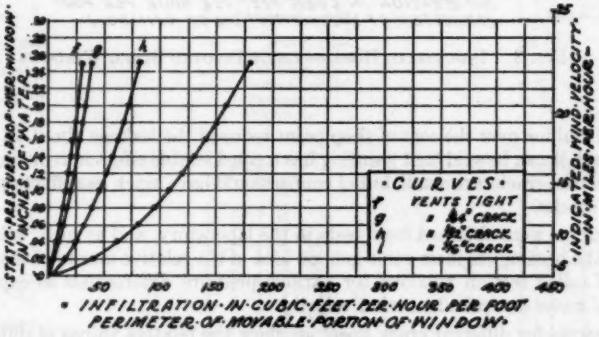

FIG. 2. HEAVY CASEMENT SECTION PROJECTED STEEL WINDOW

leakage for various pressure differences, combined with different crack openings of various types of Fenestra steel windows. The tests were made in the laboratory of the Engineering Research Department of the University of Michigan in a window-testing apparatus similar to that used by the Research Laboratory of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS at Pittsburgh.

The windows tested were all of the pivoted or swinging ventilator type. The crack opening indicated on the curves is the thickness of shims placed between the weathering contacts at the swinging edge of the ventilator. For the tight closed condition, the contacts were adjusted to a degree representing the best that could readily be obtained in manufacture and installation. Fig. 5 presents some information about the windows tested. They are also shown in Fig. 11.

The data from which the curves are obtained are for windows covered with three coats of paint—the coat of shop paint applied before leaving the factory, and two additional coats representing usual practice in installation. Some tests made especially to ascertain something about the effect of paint showed that the addition of two coats of paint over the shop coat on a heavy casement section projected window, reduced the leakage about 12 per cent. One coat of paint applied to a

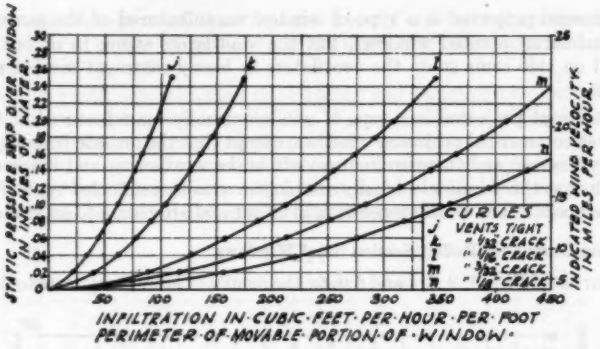
STATIC PRESSURE DROP OVER WINDOW IN INCHES OF WATER.
INDICATED WIND VELOCITY IN MILES PER HOUR.
CURVES
j VENTS TIGHT
k " 1/32" CRACK
l " 1/16" CRACK
m " 3/32" CRACK
n " 1/8" CRACK
INFILTRATION IN CUBIC FEET PER HOUR PER FOOT PERIMETER OF MOVABLE PORTION OF WINDOW.

FIG. 3. INDUSTRIAL HORIZONTALLY PIVOTED STEEL WINDOWS

sidewall mullion over the coat of shop paint reduced the leakage about 15 per cent. In general, it can be said that painting has a considerable effect in reducing leakage when leakage cracks are small, but of course would have much less effect upon larger eakage cracks.

The curves were obtained from tests in the laboratory, and as such, will serve to furnish the heating engineer some general idea of the relative merits of the different types of rolled section windows for various pressure differentials as expressed in inches of water or equivalent wind velocity.

The curves for different crack openings show the relative values of different degrees of weathering or lack of weathering of the ventilators, and are to be associated with the data of Table 1, or other data similarly obtained.

By means of these curves, the engineer can compare windows of the same type

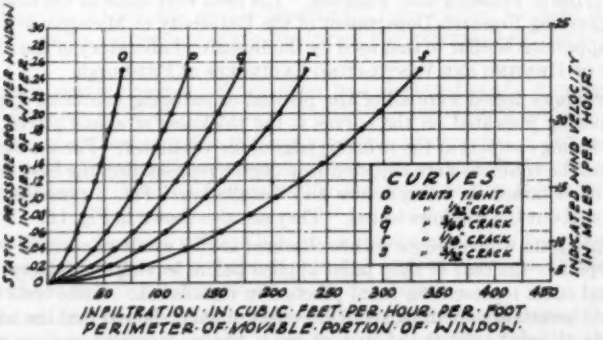
STATIC PRESSURE DROP OVER WINDOW IN INCHES OF WATER.
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FIG. 4. COMMERCIAL AND ARCHITECTURAL PROJECTED STEEL WINDOWS

as built by different manufacturers, based upon his knowledge of their design and manufacture of such windows, or upon his general experience and observation of such windows actually installed in buildings. Furthermore, he can compare the data of these curves with similar data available on wood windows, plain or weather-

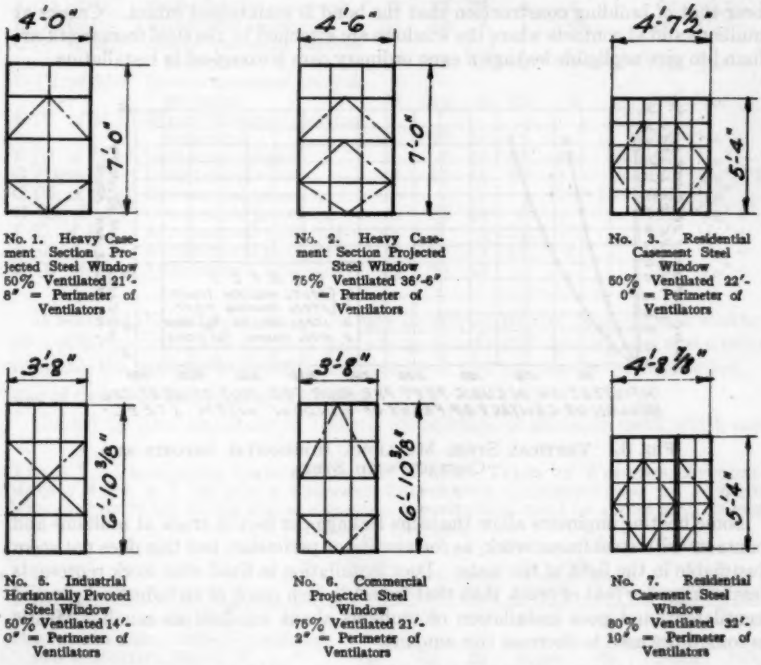
4'-0"
7'-0"
No. 1. Heavy Casement Section Projected Steel Window 50% Ventilated 21'-8" = Perimeter of Ventilators
4'-6"
7'-0"
No. 2. Heavy Casement Section Projected Steel Window 75% Ventilated 36'-6" = Perimeter of Ventilators
4'-7½"
5'-4"
No. 3. Residential Casement Steel Window 50% Ventilated 22'-0" = Perimeter of Ventilators
3'-8"
6'-10⅜"
No. 5. Industrial Horizontally Pivoted Steel Window 50% Ventilated 14'-0" = Perimeter of Ventilators
3'-8"
6'-10⅜"
No. 6. Commercial Projected Steel Window 75% Ventilated 21'-2" = Perimeter of Ventilators
4'-8⅞"
5'-4"
No. 7. Residential Casement Steel Window 80% Ventilated 32'-10" = Perimeter of Ventilators

FIG. 5. TYPES AND SIZES OF SOLID SECTION STEEL WINDOWS TESTED

stripped, and with double hung steel windows or with other types of windows which have been tested or may be tested in the future. Incidentally, the testing of windows based on one condition of crack opening has little value for comparisons.

In using the data of the curves, it must be remembered that the leakage is given per foot of crack. The total window leakage must be figured upon the entire crack perimeter, to which is to be added such mullion and frame leakage, when the window is installed in steel, as may be determined from the curves of Fig. 6. The tests indicate that when steel windows are calked with mastic, as is the common practice with residential casements, heavy section casements, heavy casement section projected, and possibly architectural projected, or grouted with cement, as is the common practice with industrial pivoted windows, the frame leakage is negligible.

In figuring wood windows, the frame and elsewhere leakage is to be added to the crack leakage to obtain the total.

As stated above, in the steel window there will be little or none of the frame leakage often found in wood windows, because the steel framing is usually installed in the opening with grout or mastic, and the coefficient of expansion of steel is so near that of building construction that the bond is maintained intact. Cracks at mullions and at contacts where the windows are attached to the steel framework are found to give negligible leakage if even ordinary care is exercised in installation.

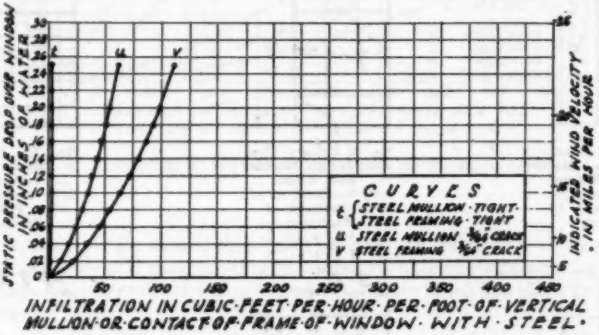
STATIC PRESSURE DROP OVER WINDOW IN INCHES OF WATER
INDICATED WIND VELOCITY IN MILES PER HOUR
CURVES
t STEEL MULLION TIGHT STEEL FRAMING TIGHT
u STEEL MULLION 1/64 CRACK
v STEEL FRAMING 1/64 CRACK
INFILTRATION IN CUBIC FEET PER HOUR PER FOOT OF VERTICAL MULLION OR CONTACT OF FRAME OF WINDOW WITH STEEL

FIG. 6. VERTICAL STEEL MULLIONS, HORIZONTAL IMPOSTS AND CONTACT WITH STEEL

Some heating engineers allow the same leakage per foot of crack at mullions and contacts with steel frame work, as for ventilator perimeter, but this does not seem justifiable in the light of the tests. Poor installation in fixed steel work represents less leakage per foot of crack than that from 1/32-inch crack of an industrial pivoted ventilator; and poor installation of mullions about one-half as much. Mastic is sometimes used to decrease this amount.

Measured Crack Widths Found in Rolled Section Steel Windows

Crack width is a quantity that is capable of being readily inspected and measured, and serves as a means of checking up on the manufacture and installation, whereas it is practically impossible to check up an installed window on any specification of air leakage.

In order to ascertain what crack widths might be expected in steel windows of the class included in this paper, a number of measurements were made in eight buildings at the University of Michigan and in a few buildings in Detroit. No attempt was made to examine all of the windows of a building, but only such as were readily accessible and in sufficient number to give fairly representative figures. Several types and makes of windows were measured as they were found in the building. The measurements are presented in Table 1. These figures, while not advanced as representative of steel window construction throughout the country, give some idea of what crack widths are found in practice.

TABLE 1. MEASURED CRACK WIDTHS OF STEEL WINDOWS IN SERVICE

Building Designated by Letter	Type of Window	Number of Ventilators Having Crack Width Indicated Which Represent the Average of a Number of Trials at Edges of Ventilators: 0.006″	1/64″	1/32″	1/16″	1/8″	1/4″	Total No.	Avg. Crack
A (U. of M.)	Heavy section casement	7	28	25	4	4	...	68	1/32″−
B (Detroit)	Residential casement	56	39	6	1	...	...	102	1/64″−
C (U. of M.)	Heavy casement section projected	..	8	12	9	7	...	36	3/64″+
D (U. of M.)	Heavy casement section projected	58	214	6	10	2	...	290	1/64″
E (U. of M.)	Heavy casement section projected	77	127	10	..	...	...	214	1/64″−
F (U. of M.)	Industrial pivoted	..	7	19	30	35	6	97	3/32″−
G (Detroit)	Industrial pivoted	16	45	46	27	11	15	160	1/16″−
C (U. of M.)	Commercial projected	..	...	..	..	128	103	231	3/16″
H (U. of M.)	Commercial projected	..	80	24	6	...	...	110	1/64″+
I (U. of M.)	Architectural projected	43	41	5	21	...	...	110	1/64″+
J (U. of M.)	Architectural projected	6	53	13	10	6	...	78	1/32″−
K (U. of M.)	Architectural projected	76	90	13	..	...	...	180	1/64″−

It is hoped that other investigators may contribute similar data on crack widths, so that in due time there will have been accumulated a sufficient amount of statistics to enable the engineer to specify maximum crack width on any given installation.

Use of Curves in Determining Infiltration

Guided by data like those of Table 1, an estimate of probable crack width can

TABLE 2. CALCULATED INFILTRATION FOR VARIOUS TYPES OF WINDOWS, APPROXIMATELY 4 FT. X 7 FT. FOR A PRESSURE DIFFERENCE CORRESPONDING TO A WIND VELOCITY OF 20 MILES PER HOUR, AND FOR A VENTILATION AREA OF ABOUT 50% OF THE WINDOW OPENING

Type of Window	Crack Width (Chosen)	Crack Length: Frame	Sash	Leakage Cubic Feet per Hour per Foot of Crack: Frame	Sash	Elsewhere	Total
Residential casement, Fig. 1	1/32″	20	22	None	99	None	2180
Heavy casement, section projected, two ventilators, Fig. 2	1/32″	22	22	None	68	None	1500
Industrial pivoted, one ventilator, Fig. 3	1/16″	22	14	None	300	None	4200
Architectural, projected, two ventilators, Fig. 4	3/64″	22	14	None	146	None	2040
Double hung steel, unlocked not weatherstripped, Houghten & O'Connell, Nov., 1927 JOURNAL, Curve *D*, p. 650	..	22	26	None	...	...	3420
Double hung steel, unlocked and weatherstripped, Houghten & O'Connell, Nov., 1927 JOURNAL, Curve *B*, p. 650	..	22	26	None	...	...	1500
Wood, average, plain, uncalked frame, Houghten & Schrader, Feb., 1924 JOURNAL, Table 2, p. 132	..	22	25	38.8	202	456	6350
Wood, rib weatherstripped, Houghten & Schrader, Feb., 1924 JOURNAL, Table 2, p. 132	..	22	25	38.8	48.5	456	2520

be made for any chosen type of window. Referring then to the appropriate curve for that type of window and using the crack width considered as representative, the infiltration per foot of crack for any pressure difference can be determined, and after the crack length has been determined, the total leakage for the window can be computed.

The tests from which the curves were plotted were not carried beyond a pressure difference corresponding to an equivalent wind velocity of about 25 miles per hour. This includes the range of pressures most usually met with, and it seemed better to represent this range by a reasonably large scale rather than to minimize it by presenting results over a wider range within the same limits of space available for

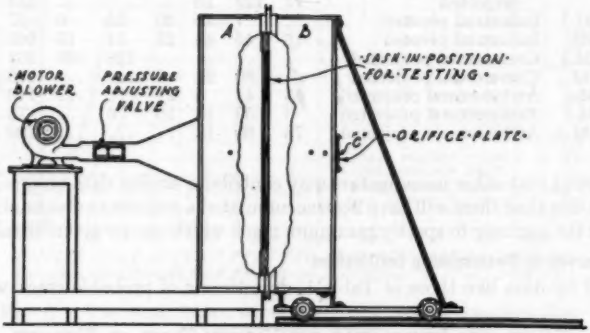

FIG. 7. DIAGRAM OF APPARATUS

the curves. Inasmuch as the curves become practically straight lines in the regions of higher values, they may be readily extended to cover extreme cases.

As an example of the computation of leakage, and to serve somewhat as a comparison among different types of windows, Table 2 has been prepared. The calculations are for a pressure difference corresponding to an indicated wind velocity of 20 miles per hour. Computations for a double hung metal window and for double hung wood windows, both weatherstripped and plain, from data available, have been included in this Table.

As will be noted, the figures for double hung wood windows have been arrived at by using the paper by Houghten and Schrader in the February, 1924 JOURNAL, instead of THE GUIDE, since the latter does not give the values for rib-stripped windows, and apparently does not include elsewhere leakage. Computations, based on Part I of Table 14, p. 47 of the 1928 GUIDE, would give a figure of 5880 cu. ft. per hour for the average plain wood window with uncalked frame, and 1940 cu. ft. per hour for the average weatherstripped wood window with uncalked frame.

Pressure Difference

The force that causes infiltration is the difference between the pressure against the inside face of the window and that against the outside face. It is a very com-

plex quantity arising out of a combination of a number of influences including the wind velocity and direction with respect to the window, the proximity of other structures as they affect the wind, the temperature inside and outside, the height of building, the distance of the window from the ground, the interior construction whether single or multiple story, the freedom of air communication between stories

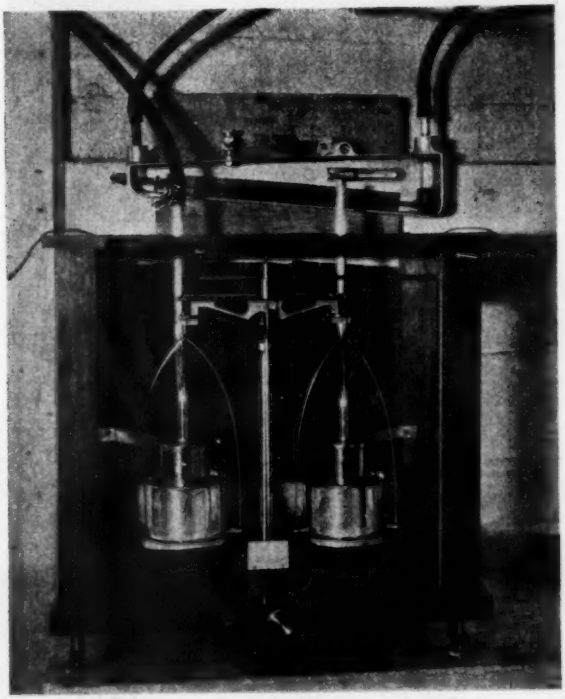

FIG. 8. THE EMSWILER DIFFERENTIAL PRESSURE GAGE WITH AN ELLISON DIFFERENTIAL SLOPE GAGE MOUNTED ABOVE

and between the room containing the window and the rest of the space on the same floor, and the means employed for ventilation whether mechanical or natural.

If the wind blows directly against the face of a building, a pressure state will be produced greater than that which would exist there if there were no wind. The maximum increase of pressure is expressed approximately by the equation

$$p = 0.00048\ M^2$$

where p is in inches of water and M is wind velocity in miles per hour. The pressure of the wind will vary considerably over the face of the building, being usually greatest toward the top and in a zone midway between the corners.

If the wind comes obliquely against a surface, the pressure will be greatest near

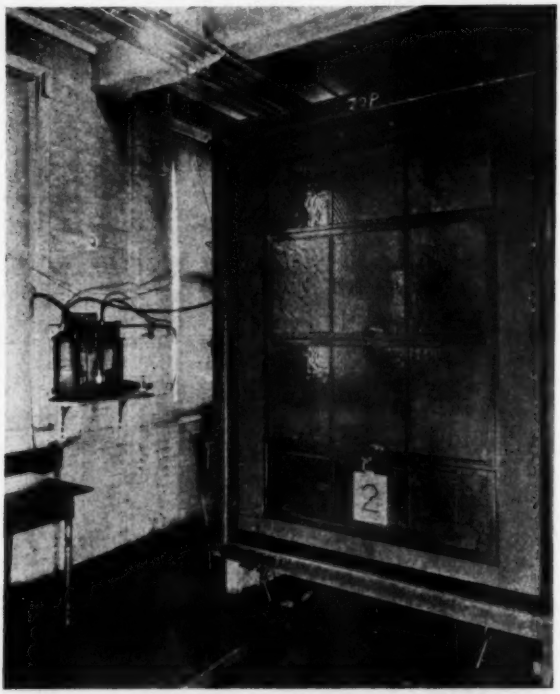

FIG. 9. WINDOW WITH WOODEN FRAME IN POSITION FOR TESTING

the corner that splits the wind and will diminish along the face.[3] Thus it would be possible in a building that was perfectly air tight on all sides except the one against which the wind is blowing obliquely, to have inflow through windows in the vicinity of the windward corner, and outflow through those near the leeward corner. The mean pressure of the wind upon a surface against which it blows at an angle may be roughly considered as varying with the sine of the angle, until the angle becomes about 10 deg. when the state changes from pressure to suction.

[3] See paper by W. C. Randall, "Airation of Industrial Buildings," TRANSACTIONS OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 34, 1928, p. 159.

On sides or roof adjacent to the corners from which the wind leaps away from the building, there will be a suction or partial vacuum, of a magnitude of approximately 75 per cent of the value given by the equation above for pressures. Where the wind blows parallel to a surface, the pressure state is neutral, that is it is equal to what it would be if no wind were blowing. There will be some slight suction at the leeward end or side of a building.

The wind, therefore, operates to create regions of pressure or vacuum about the

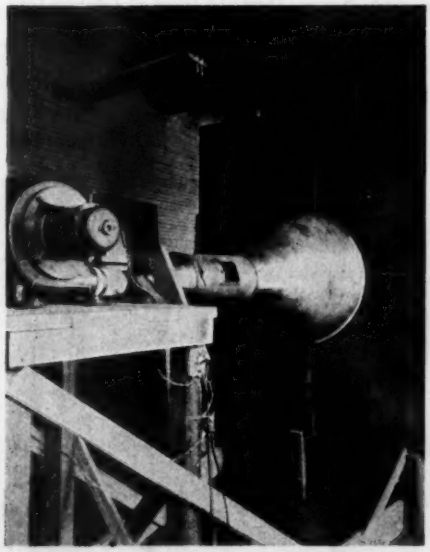

FIG. 10. VIEW SHOWING BLOWER, PRESSURE CONTROL VALVE AND ARRANGEMENT FOR OPERATING THE VALVE BY REMOTE CONTROL

exterior of a building, as compared to the normal or neutral barometric pressure state that would exist in those regions if the air was still. These pressures or suctions are not necessarily the forces that produce infiltration, since it is the difference of pressure on the inside and outside of an opening that causes flow—not the external state alone.

Other structures in the proximity of a building may greatly modify the action of the wind, particularly in reducing the maximum intensity of the pressure and suction.

Even without any wind, a difference of temperature inside and outside will cause the pressure state inside to be less than that outside at the ground, and greater

near the roof, and inflow will occur at lower windows and outflow at upper windows.[4] If the building is tall and open throughout from bottom to top, or if arranged in stories in free communication from one to another, and if the temperature difference is great, the pressure difference created at a point near the ground and also at a point near the roof may be considerable. Thus, in a building 200 ft. high with 70 deg. fahr. difference in temperature, this force alone causing inflow at the ground and outflow at the top, may easily exceed 0.20 in. of water, which is the equivalent of a twenty-mile wind. If the building is multiple storied and there is absolutely no communication between stories, then the force of temperature difference is effec-

FIG. 11. ASSEMBLY OF WINDOWS TESTED

tually nullified, or rather reduced to an amount proportional to the height of a single story. However, there is always some communication by means of stairs and otherwise, so that the force of temperature difference is always operative in some degree.

If the wind blows against a window of a building that is tightly sealed at all other points of possible ingress or egress of air, there will be no continuous infiltration at the window, because the temporary excess of pressure outside will soon be equalized by a momentary inflow. If the building has an outlet of exactly the same area as the presumed infiltration area of the window, and this outlet opens into a region of neutral pressure, then the pressure in the room will be half as much as that produced by the wind outside. Infiltration will take place through the window, but

[4] See paper by J. E. Emswiler, "The Neutral Zone in Ventilation," TRANSACTIONS OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 32, 1926, p. 59.

with only half the force of the wind pressure. Something like this is what occurs in any building. Whatever air gets in at inflow points must escape somewhere else. In order to force the air out, there must be a greater pressure inside somewhere than that which prevails immediately outside. The inside pressure automatically assumes a value that will give the necessary head for outflow through openings available, so that the outflow quantity always balances the inflow.

A weatherstripped inside door in an apartment will effectively retard infiltration through windows, because it makes it more difficult for the air to get out, and thus automatically increases the inside pressure opposing the wind. On the other hand,

FIG. 12. THE TEST IN PROCESS

an open louver or transom in the door will increase infiltration. A fan in the kitchen, exhausting air, will tend to increase infiltration.

If a building is exposed to wind, a considerable part of the exterior is in a suction state. But it is probable that in a building not equipped with roof openings, as in the factory type, the interior pressure is usually higher than neutral, so that the force causing infiltration is less than that of the computed wind pressure.

As between wind and temperature difference, the wind is, no doubt, the more powerful agent in the extreme. But in a tall building, the outflow tendency at the upper levels caused by temperature difference is a factor of importance operating to greatly reduce infiltration at the top floors. On the other hand, at the lower levels, the wind and temperature difference cooperate to increase infiltration. How-

ever, the wind is usually much less effective near the ground because of the presence of other structures.

This whole question of pressure difference is fundamental to the problem of infiltration. Some excellent data on infiltration for all possible ranges of pressure difference are being accumulated, but much information about what pressure difference should be used in determining the probable amount of infiltration for any given case has not as yet been advanced. It would seem then that further research on the general subject should be directed at least in part toward this phase of the problem.

While numerous factors contribute in a very complex way to determine pressure difference, the actual measurement of it in a building is a simple thing. What is needed is a recording device that can be set up in various places in different buildings to operate more especially during the season of extreme weather conditions. The accumulation of records from a number of instruments would in time furnish definite information on pressure difference which, taken in conjunction with laboratory data now available, and crack widths guaranteed by manufacturers, would make it possible to definitely determine infiltration.

Following a suggestion received from the paper by Messrs. Houghten and O'Connell in the November, 1927 JOURNAL, a number of observations were made during April of this year, of the actual prevailing pressure difference as found in the University Hospital at Ann Arbor. These data have been taken chiefly for the purpose of ascertaining the feasibility of the plan, and represent manual observations for periods of about 20 minutes at each station, at one-minute intervals. The readings obtained do not represent extreme conditions of either wind or temperature difference, although on one day a wind velocity of over 20 miles per hour was recorded by the anemometer at the University Observatory. Some of the averages of the readings are given in Table 3.

TABLE 3. AVERAGES OF SOME READINGS, OF PRESSURE DIFFERENCE ACROSS WINDOWS OF UNIVERSITY HOSPITAL, ANN ARBOR, AS OBSERVED ON THREE DIFFERENT DAYS AT CORRESPONDING STATIONS AT 2ND AND 6TH FLOORS

Date	Average Wind Velocity	Station *A*		Station *B*		Station *C*	
		2nd Floor	6th Floor	2nd Floor	6th Floor	2nd Floor	6th Floor
Apr. 17	5.3	+0.009	+0.013	+0.020	+0.003	+0.024	−0.036
Apr. 18	11.3	+0.006	−0.007	+0.054	+0.001	+0.010	−0.037
Apr. 19	21.0	+0.516	+0.380	+0.060	+0.037	+0.159	+0.099

In the above table the plus (+) sign indicates tendency for inflow, and (−) sign, outflow.

The different floors of the hospital were not in open communication. The readings at Station *C* were taken at windows in the stairwell, and are naturally influenced to a greater degree by temperature difference than are those of Stations *A* and *B*.

It will be noticed that the pressure difference varies widely, the values ranging all the way from −0.037 to +0.516, the latter value corresponding to an equivalent wind velocity of about 33 miles per hour. It is significant that in every case, except one in Table 3, the inflow tendency at the second floor was always greater than that at the sixth floor, indicating the activity of temperature difference, and probably also the influence of a fan ventilation system serving a part of the building. The

height between the second and sixth floors is about 45 ft., and the outside temperature was about 40 deg. fahr. A recording device is being made whereby more extensive observations can be carried on.

Due to the fact that there is not a constant definite relation between the difference in pressure between the outside and inside face of all windows and the velocity of the wind, as measured at some observation point, one must hesitate to use the definite pressure difference as being equivalent to the assumed wind velocity. This is particularly true if this is transferred to infiltration and in turn to B.t.u.'s. In other words, one cannot assume with accuracy that there is always an actual saving in B.t.u.'s required to heat the infiltering air comparable to the difference in leakages shown on the curves.

Relation of Infiltration to Heating and Ventilation

It is common practice, to provide additional direct heating surface to supply the heat necessary to warm the cold infiltrating air to room temperature and to charge up the installation of extra radiation and the heat consumed therein, as a loss attributed to infiltration. But infiltration is ventilation and, within reasonable limits, it would seem that this heat should be charged to ventilation. This is exactly what is done automatically in naturally ventilated buildings. With considerable wind, the ventilators on the windward side are closed; and inflowing air on that side is reduced to infiltration which then becomes the only means of ventilation. The heat employed in warming the incoming air is not a loss but is chargeable to ventilation. In a building that is mechanically ventilated, there appears to be no good reason why the amount of cold air drawn in by the fan and heated up should not be reduced as infiltration increases on a windy day.

Every building should have adequate ventilation which usually means exchanging inside for outside air. If a naturally ventilated building had windows perfectly air tight against infiltration, some windows would then have to be opened to provide the necessary air for ventilation during the hours of occupancy. In a mechanically ventilated building it is equally true that if windows were perfectly air tight, the fans would have to draw in more outside air to be heated up to compensate for the loss of ventilation by infiltration.

Steel windows, particularly some types, can be made weathertight to almost any practical limit desired, but in view of what has been said, there would seem to be no economic justification in seeking to secure too great a degree of weathertightness. How far it is desirable to go depends upon the service of any given building. In office buildings and schools, ventilation is not necessary during the hours of non-occupancy and infiltration then represents a heating loss, although, as has been pointed out, it may not represent a loss during the hours of occupancy. In a factory building, which may be operated 24 hours a day, and where temperatures are usually lower, infiltration in moderate amounts will mean no heat loss. In dwelling houses and apartments, where sleeping room windows are open during the night, infiltration in such rooms represents no loss during those hours, while in the daytime in cold weather, the only means of ventilation is by infiltration, of which there must be some; otherwise windows would have to be opened for that purpose. The point to be made is that infiltration in a moderate degree is in many cases a necessity, and not a source of heat loss, and amounts representing heat savings by reduction of infiltration should be considered with considerable caution.

Apparatus and Method of Testing

The apparatus used in these tests is shown in Fig. 7 and is very similar to that developed by the Laboratory at Pittsburgh. It is built of 20-gage sheet iron over an angle iron frame. The chamber *A* is stationary, while chamber *B* is constructed upon a wheeled carriage which allows it to be easily moved back, giving access to the window. All of the windows that were to be tested were installed in wooden frames of the same over-all dimensions, so that window and frame were handled as a unit and could be mounted in the tester or removed quickly and conveniently. The wooden frame was bolted to a stationary steel frame in chamber *A*. This joint between the window and wooden frame, and that between the wooden frame and stationary steel member were sealed with mastic. Fig. 9 shows a window bolted to the stationary frame of chamber *A* and Fig. 11 shows an assembly of the windows tested and referred to in this paper.

Care was taken to make chamber *B* as tight as possible. All of the fixed joints are welded and painted, while the joint between *A* and *B* is sealed with a soft sponge rubber packing. Experiment showed that chamber *B* was not absolutely air tight, but a method was developed for determining the slight leakage that did occur, and the corrections have been applied.

A static air pressure equivalent to any desired wind velocity is produced in the pressure chamber *A* by a small motor blower and the air that leaks through the window or other construction is collected in chamber *B*, and, as it passes through the orifice *C*, its volume is determined by the well-known orifice method established by R. J. Durley (*A.S.M.E. Transactions*, Vol. 27, p. 193) and others.

The pressure drop through the orifice was determined by an extremely sensitive differential type of gage designed particularly for this research work. Fig. 8 illustrates the Emswiler gage and suggests the principle of operation. The fixed chambers or cylinders on the two sides, to which are connected the rubber tubing at the top of the instrument, have their lower open ends dipping into liquid contained in corresponding cups which rest upon the pans of the sensitive balance. It will thus be seen that the pressure difference is virtually weighed by means of a chemical balance. The gage will respond to variations in pressure as small as 0.0002 in. of water.

The pressure drop through the window was measured by an Ellison differential slope gage graduated to 0.01 of an inch of water.

A slide over the intake of the blower was used as a primary control of the pressure drop through the window, while the pressure adjusting valve, shown in Fig. 10, served as a vernier regulation of the same pressure. An arrangement of rope and pulleys enabled the observer at the two gages to adjust and hold with ease any desired pressure drop through the window at an absolute value, while the pressure drop through the orifice was being determined.

The test of each window was made by regulating the pressure controls to give the desired pressure drop through the window as indicated by the slope gage, and while this pressure was maintained by manipulation of the adjusting valve, the pressure drop through the orifice was determined by the sensitive differential gage. By repeating the test for a large number of pressure differences through the window, data were obtained for plotting a curve showing air leakage through the window in cubic feet per hour, for pressure differences in inches of water or equivalent wind

velocity. As readings were taken, the pressure readings of one gage were plotted against the pressure readings of the other and a curve constructed through the points. If some points did not fall on the general smooth curve, the readings of these points were checked by repeating that particular point. All velocities and volumes given in this report are for air under standard conditions of 29.92 in. of mercury, a dry-bulb temperature of 68 deg. fahr. and 50 per cent relative humidity.

The authors wish to acknowledge the work of L. W. Leonhard and J. A. Grant, who conducted the laboratory work and made the field survey.

Bibliography on Infiltration through Windows

Window Leakage, by Stephen F. Voorhees and Henry C. Meyer, Jr., TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 22, 1916, p. 183.

A Study of Infiltration of Air in Buildings, by O. W. Armspach, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 27, 1921, p. 121.

Air Leakage through the Openings in Buildings, by F. C. Houghten and C. C. Schrader, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 30, 1924, p. 105.

Air Leakage around Window Openings, by C. C. Schrader, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 30, 1924, p. 313.

Further Data on Infiltration of Air through Building Openings, by C. C. Schrader, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 31, 1925, p. 85.

Some Studies in Infiltration through Windows, by A. C. Armstrong, JOURNAL AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, July, 1927.

Air Leakage Studies on Metal Windows in a Modern Office Building, by F. C. Houghten and M. E. O'Connell, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 34, 1928, p. 321.

DISCUSSION

F. H. BURKE (WRITTEN): The paper presented by Messrs. Emswiler and Randall is an excellent example of practical and timely research. From first to last, this paper is packed with valuable data and logical conclusions, all of which are admirably presented.

Mention is made of the rather widespread opinion that rolled steel sections for windows are less weathertight than window sections of wood. The Standard Radiation Estimating Table of the *Heating and Piping Contractors National Association* tabulates the infiltration of double hung steel sash and fenestra as twice that of double hung wood sash. It would appear that this widespread opinion has, to some extent, received the stamp of authority, though I doubt that any engineer of experience would be misled.

The authors' observations regarding frames distorted in shipment and handling, and of steel windows with excessive crack widths due to the hardened mortar and plaster chunks should be given heed by architects as well as by engineers. Nor is it out of reason to conclude from these observations, that the engineer should inspect those factors outside his work which may affect the proper working of a heating and ventilating system, and call the architect's attention to faulty construction.

That portion of the paper under the heading Relation of Infiltration to Heating and Ventilation merits special consideration. It is to be hoped that the deduction set forth will bear fruit and be widely applied. Of late we have been strenuously advocating the insulation of walls and roofs to save heat loss. This is as it should be. But here we have a warning that we should not carry the stoppage of heat

loss to extremes by stopping altogether the infiltration loss at windows, lest we also stop much needed ventilation.

At the end of the paper the Bibliography on Infiltration through Windows will have added value by including also the paper of Messrs. Emswiler and Randall.

EDWIN S. HALLETT (WRITTEN): This paper is a valuable contribution to the literature now so rapidly appearing on the subject of infiltration. The table on p. 533 especially represents a great outlay of time in compiling the data on actual cracks, in the various types of steel windows.

In making use of these tables the architect and engineer will discover the wide variation in the crack, especially in the industrial pivoted and the commercial projected. This does not properly represent the present state of the manufacturing process but rather the product of several firms some of which do not use precise methods in the manufacture. Steel sash will be made tight when the demand for it becomes insistent. This demand must come from engineers who have learned of its value in other branches of research of this Society.

The comparison of the crack leakage of steel sash with wood does not make a good showing for steel in the table on p. 533. The calculated infiltration of wood sash and rib weatherstrip is 48.5 cu. ft. per hour, the lowest reported. However attention should be called to the fact that steel sash has been designed generally for setting in mortar, and there is seldom any frame leakage, whereas wood frames are not generally calked at all. The advantages gained by steel frames set in mortar are more than the losses from greater crack of the steel sash as shown. Evidently the choice of steel or wood sash will be made upon other reasons than that of weathertightness.

The paragraph devoted to the relation of infiltration to heating and ventilation calls for most emphatic protest. Infiltration is not ventilation. Infiltration whether inward or outward is injurious to ventilation and produces a loss. Ventilation places a house under fan pressure and leakage at the window in still outside air increases the air delivered to the room from the fan. If a wind is blowing the leakage will be inward and the fan delivery will be reduced and the air distribution in the room disturbed and the temperature reduced. Inleakage brings dirt, sulphur gas and the street odors, so that infiltration in any degree is a defect in the building construction.

Those architects who still build vent stacks on their buildings for wasting all the air of ventilation will not be interested in small window cracks nor frame calking. The owner will however be compelled to shut it all down to save fuel.

It is not probable that there is an inherent advantage of steel over wood or wood over steel in designing perfectly tight windows. The refinements of weather strips for wood sash has placed that temporarily in the lead, but the enterprise shown in steel sash industry points to the production of a sash practically perfect and proof against all infiltration.

PROF. G. L. LARSON: I feel that this paper is a very excellent contribution to our data on infiltration. We have lacked information as far as THE GUIDE is concerned on the matter of steel windows and especially on steel casement windows.

There are a number of points that occurred to me that might well be brought out here in order that we may make the paper a little more valuable in working it up for future use in THE GUIDE.

Referring to p. 534 where Table 14 of THE GUIDE 1928 is referred to, I think the authors will find on further investigation that Table 14 does include elsewhere leakage. Perhaps Mr. Houghten can check me on this: I think Table 14 also gives an average of interlocking and rib strip rather than just rib strip alone. These items are not clear in THE GUIDE, but I think the authors will find them to be true on further investigation.

I also note that the authors make their comparisons with wood windows, not calked. I think it is true nowadays that practically all wood windows put in brick walls are calked, and it would give more nearly the right conditions of comparison if comparisons had been made with calked frames set in brick walls.

I also want to refer to the statement on the first page where the author states "for a ventilating area equal to 50 per cent of the window area, the crack perimeter of a steel window will vary between 60 per cent and 90 per cent of the crack perimeter for double hung windows."

I think a comparison made on the basis of light area instead of ventilating area would bring different results. For instance, take a given window opening in a wall and it is decided to put in a casement window in that opening rather than a double hung window. In such a case I think it will be found that the perimeter of the crack openings for the casement window is greater than it would be for the double hung window. This is true for steel as well as wood casements.

I would like to ask how the windows were closed before the tests. I got the impression that in each case the window was adjusted so that it fitted equally all around, being pressed against the space gages so that it had an equal opening through the entire perimeter. It has been my experience with casement windows that they are closed by a lock near the middle of the window and may fit very closely near the lock and have a very poor fit at the corners away from the lock.

I think it would clear up the paper a little bit to have a statement as to how they were arranged before the tests were made.

One other point I wish the authors had brought out a little more clearly, and that is, just what in their opinion and experience is the maximum crack that should be allowed for in designing calculations of these types of windows. I think they purposely avoided it and put it up to the designer to choose, but I am thinking in terms of the chairman of the Infiltration Committee of THE GUIDE as to what values should be used there, and that is what I am being asked so I am passing the responsibility to the authors, to develop a table that will give us results that will be workable for the average man that is trying to use THE GUIDE.

J. E. EMSWILER: In reference to one point that Mr. Hallett has made, *viz.*, that infiltration is not ventilation: of course, it is not contended that infiltration in any excessive degree is ventilation, but the point that the authors have attempted to make is that it is not only uneconomical to attempt to reduce infiltration below a certain point, but in many circumstances it would not be desirable to do so, even with the question of economy not under consideration. For instance in naturally ventilated buildings, of which nearly all dwelling houses are examples, there must be some air let in from the outside, and the only air that gets in from the outside is by way

of infiltration or through the natural opening of doors, inlets and outlets, for ingress and egress to the building. In fan ventilated buildings, of course, infiltration tends to disturb the fan system, but even there infiltration to a degree is certainly not harmful and so long as air gets in and does not disturb the system, it seems to me it is legitimate to consider it as a portion of the ventilation.

W. C. RANDALL: With reference to the rib type of weather stripping used in the comparisons, as questioned by Professor Larson, we made investigations of the general types of weatherstripping generally used, and we found in checking up with the representatives of four manufacturers that over 80 per cent of the weatherstripping was ribbed strip, not the interlocking strip. That is why we preferred to think it was a little more practical to use the ribbed strip figures.

In reference to the calking of windows, we checked with people who make a specialty of calking windows in Detroit, and found that less than 10 per cent of all wood windows which are manufactured and installed are calked. I would say that in brick construction referred to by Professor Larson, if 25 per cent of the windows were calked, that is a very high figure at the present time. I don't think enough is known of the infiltration of air through the windows that people realize the advantage of calking at the present time. I think the paper by Professor Larson will go a long way toward correcting that situation. We therefore felt it more practical to use uncalked frame figures.

With reference to the crack, and something which can be used in THE GUIDE, I presented a table of the typical figures as we found them. In the comparison which we made with other types of windows, we used a $^1/_{32}$-in. crack for residential casements, $^1/_{32}$-in. crack for heavy casement section windows, $^3/_{64}$ in. for the architectural projected, $^1/_{16}$ in. for the industrial windows and I would say so far as the steel window manufacturers, the equivalent of that at least should be guaranteed, particularly if the window is installed by the manufacturer. At least that can be expected, and I think the figures as represented by those particular curves could be used with the provision possibly that the installation in the building has got to come within those limits of crack opening because the crack opening can be very easily checked to and measured.

With reference to Mr. Hallett's discussion on this paper, I think that he has referred particularly to schools. After all, there is a wide general application of steel windows to residential and industrial conditions that are quite different than we normally have in the school, and while his criticism was probably perfectly in order in reference to schools, the authors had in mind a little broader general application where the point made might a little more logically be true.

Incidentally with reference to the leakage of rolled section steel windows, I was talking to Mr. Hallett and they have a school in St. Louis called Lincoln School. It was referred to in White Sulphur in the discussion of Mr. Armstrong's paper and is published information. That is this: there is less leakage in this rolled section steel window installation than any other in St. Louis, and incidentally, he said the heating equipment on that school, which is for 1800 pupils, is about the same as they normally use for the 1200-pupil schools. His experience, and I am sure I interpret it correctly, more or less consolidates the conclusions of the authors that despite widespread opinion and certain authorities on the subject, there is not greater leakage through rolled section steel windows than through wood windows.

No. 817

EFFECT OF FRAME CALKING AND STORM WINDOWS ON INFILTRATION AROUND AND THROUGH WINDOWS

By W. M. RICHTMANN[1] (*Member*) AND C. BRAATZ[2] (*Non-Member*)

MADISON, WIS.

THE subject of infiltration has given rise to much discussion as to the amount of air which finds its way into buildings through and around the windows and other openings. This report is the result of a series of tests which have been carried on at the University of Wisconsin during the past year. It is the first work which has been conducted under the cooperative agreement with the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

These tests have been made to show the effect of calking the crack between the brick wall and window frame, and the effect of applying storm sash to the window. Each group was divided into two parts. The infiltration was determined through the crack for a window set in a plain 13-in. brick wall and for the same crack after the wall had been plastered. The storm sash was applied in two methods to a window which had a very small crack and clearance and to a window with a crack and clearance of more or less average size.

Description of Apparatus

The apparatus used to determine the air leakage or infiltration is very similar to that used in the Research Laboratory at Pittsburgh. Fig. 1 shows the location of the equipment with reference to the storage space for windows, doors and walls, and also illustrates the apparatus set up for a test run. The machine is built of eighteen gage galvanized iron, and consists of two main parts: the pressure chamber *A* and the collecting chamber *B*. Each of these chambers is fitted with an opening so that entrance may be had into either chamber to make adjustments after the two parts of the machine have been fastened to the wall. To facilitate setting up a wall for testing, the collecting chamber *B* and the orifice box *C* have been mounted on a small four-wheel truck which can be moved back about 10 ft. from the pressure chamber on a narrow gage track upon which it operates. This provides sufficient space to place the wall between the two halves of the machine for the tests. Chambers *A* and *B* are fastened to the bottom of the wall by means of two eye bolts

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The results of cooperative research between the University of Wisconsin and the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

Presented at Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.

hinged to the bottom side of the pressure chamber. These bolts extend through two holes in a channel bar which is attached to the bottom side of the collecting chamber and are secured by two nuts. The sides and top of the pressure and collecting chambers are fastened to the channels of the steel frame containing the wall by means of *C*-clamps. To insure that no air will escape from the joint between the steel frame and the pressure and collecting chambers, sponge rubber approximately 1 in. square in cross section has been attached to the lip of these chambers. The rubber on the collecting chamber is indicated by *A*, Fig. 2.

The artificial wind pressure is produced by a small motor-driven blower, rated at 340 cu. ft. of air per minute against a static pressure of 3 oz. of water, which is

FIG. 1. GENERAL LAYOUT OF TEST EQUIPMENT

connected to the pressure chamber. The pressure drop through the wall may be regulated by means of a damper on the inlet of the blower, a relief slide, *D*, and a sliding damper, *E*, located in the connection between the blower and the pressure chamber. This pressure is measured by an ordinary inclined draft gage, *F*, the ends of which are connected to the pressure and collecting chambers.

The orifice box *C* is fitted at one end with eight $^1/_4$-in. stud bolts equally spaced on the circumference of an 11-in. circle, to which the orifice plates are secured by means of wing nuts. The orifices, varying in diameter from $^1/_8$ in. to 8 in., are accurately machined in these plates. A rubber gasket is placed between the end of the orifice box and the orifice plate in order to eliminate any possibility of leakage at that joint.

The pressure drop through the orifice, which is the pressure differential existing

between the orifice box and the atmosphere is measured by a Whalen gage, *G*. The atmospheric pressure is determined from an aneroid barometer, and the relative humidity of the air is calculated from the readings taken from a chart on the wet- and dry-bulb recording thermometer. These instruments are designated by *H* and *J*, respectively, in Fig. 1.

The steel frames in which the walls are built were specially designed for the conditions which are encountered in this test. The frame is made of 15-in. channel iron reinforced at the corners with angles which are riveted into place. The construction was changed slightly after the first frame had been completed. Instead

FIG. 2. MACHINE OPEN WITH PLASTERED WALL IN PLACE

of the side members resting on the bottom channel which is supported by two ball bearing rollers, the side members were lengthened so that they rest on the floor, carrying the entire load of the frame and wall. The top and bottom members are butted against the side members, and are riveted to reinforcing angles. These changes are clearly shown by comparing the wall in the machine with those in the storage rack, Fig. 1. Provision was made on the frame for attaching the moving equipment. This consists of an *A* frame mounted on rollers, and a single steering roller. The construction of the frame and method of attaching it to the

wall frame is shown in Fig. 1. Tightening the nuts at the two ends of channel iron *K* draws the two legs of the frame together, lifting the wall off the floor. The steering roller is attached at the opposite end of the wall. That end is lifted by a screw jack thread cut on the vertical shaft to which the steering roller is fastened.

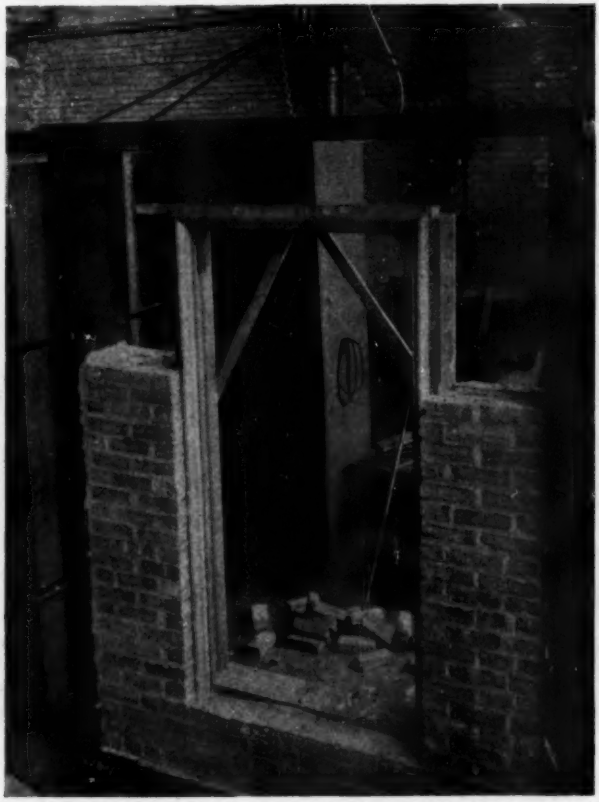

FIG. 3. WALL NUMBER ONE UNDER CONSTRUCTION

This arrangement works out very well and is a very great improvement over the two ball bearing rollers which were placed under the first frame. The *A* frame is very stable and eliminates the chances of sudden shock which might cause cracks in the completed walls.

Description of Wall and Window

The wall used in this series of tests is wall Number 1 of the proposed program of tests to be carried out at the University of Wisconsin. A box type double hung wood window frame, with sash 3 ft. x 6 ft. x 1 3/8 in., was built in a section of 13-in. brick wall. A porous type of brick commonly known as the Chicago clay brick and ordinary lime mortar were used for the construction of this wall. These materials are used very extensively for construction purposes, and it was decided upon as one of the combinations of masonry wall to be tested. The manner in which the window frame was built into the wall is shown in Fig. 3. This picture

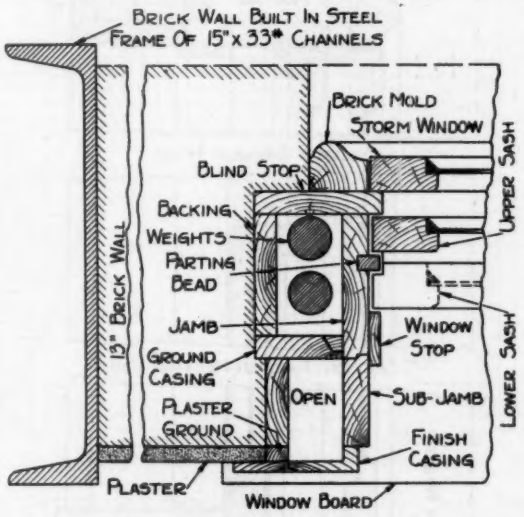

FIG. 4. HORIZONTAL SECTION THROUGH WALL AND WINDOW FRAME

was taken during the process of construction and shows the steel frame work which contains the wall section, the manner in which the brick are laid, and the small amount of mortar that was used to slush the joints between the brick.

Provision was made for applying storm sash to the window frame after the wall had been placed in the machine for test. Two types of fastenings for the storm sash were tested: one in which the storm sash was suspended from the top of the window frame by the ordinary hook and eye arrangement and held at the bottom by the arm type clamp, and the other in which the storm sash was held in place by four turn buttons screwed onto the window frame itself. The former type of fastening permits the storm sash to be opened slightly for ventilating purposes, while the latter does not permit any movement of the storm sash after it has been secured in place.

Fig. 4 is a cross section through the steel frame, brick wall and window frame showing the general type of construction of the wall under test. The first series of tests were run on the plain wall. A coat of gypsum base plaster was then applied to the wall, allowed to dry for a week, and then the second series of tests were made.

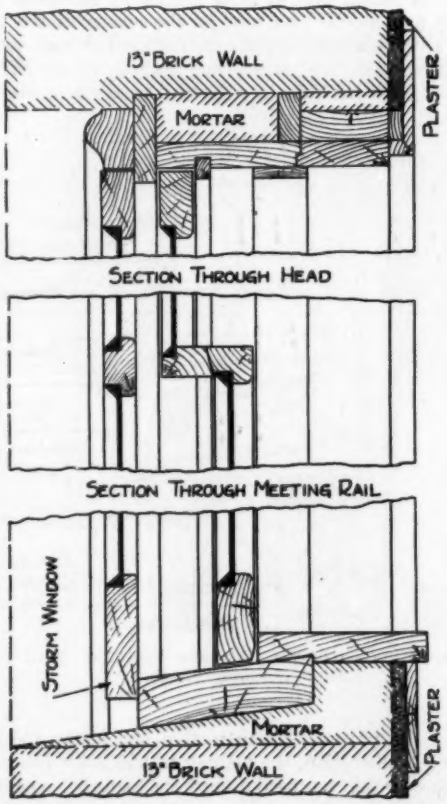

FIG. 5. VERTICAL SECTION THROUGH WINDOW FRAME

Fig. 5 is a cross-section view of the head, meeting rail and sill of the window tested. Fig. 2 shows the type of finish used on the window after the plaster had been applied.

Every precaution possible was taken to insure that the wall and window frame would represent conditions which would be comparable to those used in the actual construction of buildings. The window frame and sash were purchased from a local

lumber company, the sash were fitted and the brick wall laid by the service department of the University of Wisconsin. Any changes which were made during the test were done by the same department. Having the work done in this manner duplicated ordinary building practice very closely.

Procedure

The wall was placed in the machine, the machine clamped into place, and several preliminary runs were made to ascertain if there was any leakage through the various parts of the machine itself. When all of the leaks had been stopped, the joint between the steel frame and the brick wall was calked to insure that all the

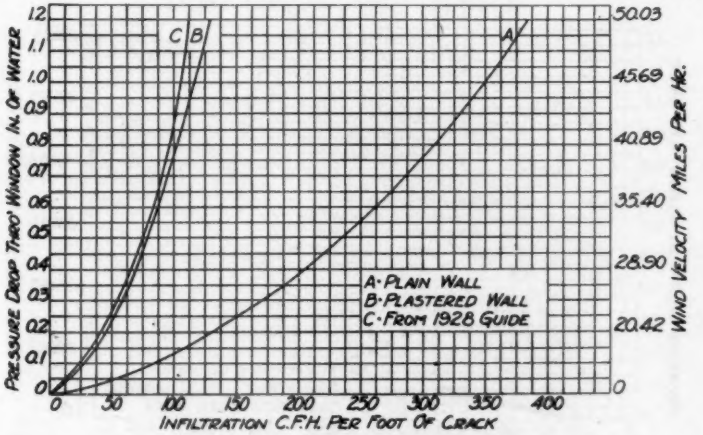

FIG. 6. INFILTRATION THROUGH CRACK BETWEEN BRICK WALL AND WINDOW FRAME

leakage must take place through the brick, through the window frame or through the sash perimeter of the window. In all cases of calking adhesive tape was first placed over the crack and this covered with a plastic calking compound. In this manner the calking could be easily removed and insured against the calking compound entering very small cracks which could not be cleaned out when a duplicate test was desired. This method proved very satisfactory and was employed during the entire series of tests.

Test data were obtained at pressure drops through the wall corresponding to increments of wind velocities of 5 mi. per hour over a range from 10 to 50 mi. per hour, inclusive. This pressure drop was controlled by varying the amount of air allowed to enter the pressure chamber from the blower. Readings of the wet- and dry-bulb temperatures and the atmospheric pressures were taken during the progress of each run. The inclined gage and the Whalen gage were read

simultaneously for each pressure after the air conditions in the machine had sufficient time to become stable.

Check runs were made on each set of conditions so that the curves represent the average of at least six separate runs, and in some cases as many as twenty-four runs. After each set of two runs the window was opened and closed several times to insure that an average value for the window closing would be obtained.

To obtain the infiltration through any one crack a series of runs were made to determine the total leakage through the wall and window as it was placed in the machine. The crack was then calked in the manner previously described and another series of runs were made. The actual leakage for the crack in question was determined by subtracting the leakage found in the second test from that in the first for a

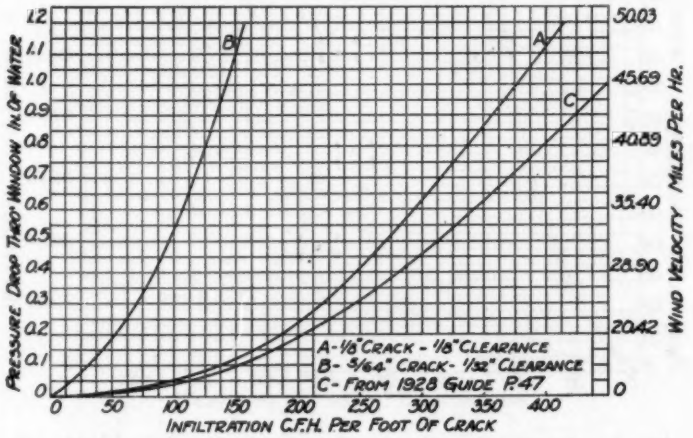

FIG. 7. INFILTRATION THROUGH SASH PERIMETER OF WINDOW

given pressure drop through the wall. In this manner each leakage could be isolated and determined in the easiest manner. During the entire test care was taken to see that the setting of the wall was not disturbed and all calking was carefully inspected to insure against leaks.

Discussion of Results

The data taken during the tests supplied the necessary information to determine the leakage through the various parts of the window and wall. All infiltration was measured in cubic feet per minute by the orifice method. These data were then reduced to infiltration in cubic feet of air at standard conditions, 29.92 in. of mercury, 70 deg. fahr. and 50 per cent relative humidity per hour per foot of crack. This gives a factor which may be multiplied by the number of lineal feet of crack in the room for which the heat loss is to be figured.

Fig. 6 shows the infiltration through the crack between the brick wall and the

window frame, *A* for the plain brick wall, *B* for the plastered wall and *C* is plotted from the data given on page 47 of the 1928 GUIDE. There is a considerable reduction of this leakage by plastering the wall, but all of the leakage may be stopped by calking the window frame in the brick wall during construction or even later at a very slight expense.

The curves plotted in Fig. 7 show the infiltration through the sash perimeter of the window, *A* for the window fitted with $^1/_8$-in. crack and $^1/_8$-in. clearance, *B* for the window fitted with $^5/_{64}$-in. crack and $^1/_{32}$-in. clearance, and *C* for the average window from data given on page 47 of the 1928 GUIDE. These curves show very

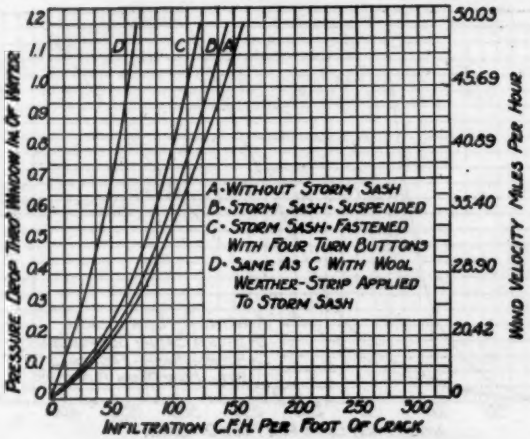

FIG. 8. INFILTRATION THROUGH SASH PERIMETER OF WINDOW WITH AND WITHOUT STORM SASH—$^5/_{64}$" CRACK AND $^1/_{32}$" CLEARANCE

clearly the increase in infiltration which accompanies an increase of the crack and clearance.

The curves on Fig. 8 show the infiltration through the sash perimeter of a window with $^5/_{64}$-in. crack and $^1/_{32}$-in. clearance before and after storm sash have been applied. Curve *A* is for the window without storm sash, *B* for the window with storm sash suspended by the hook and eye arrangement, *C* for the window with storm sash fastened with four turn buttons, and *D* is the same as *C* except a felt strip was placed between the storm sash and the window frame. This last condition could be used to advantage where the windows are fastened by means of the turn buttons.

The curves on Fig. 9 correspond to curves *A*, *B* and *C* of Fig. 8 except the window is fitted with an $^1/_8$-in. crack and $^1/_8$-in. clearance.

The storm sash used for both series of tests was fastened so that it rested against

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the window frame as tightly as possible. A crack of $^{3}/_{64}$ of an inch was left between the storm sash and window frame. This was considered to be a conservative size although some storm sash very probably have a crack which is larger than this.

The infiltration through the window after the storm sash had been applied was figured on the basis of the sash perimeter of the window and not the perimeter of the storm sash. This point should be noted as there is considerable difference between the two perimeters.

Care was taken during the entire test that conditions in the machine would be

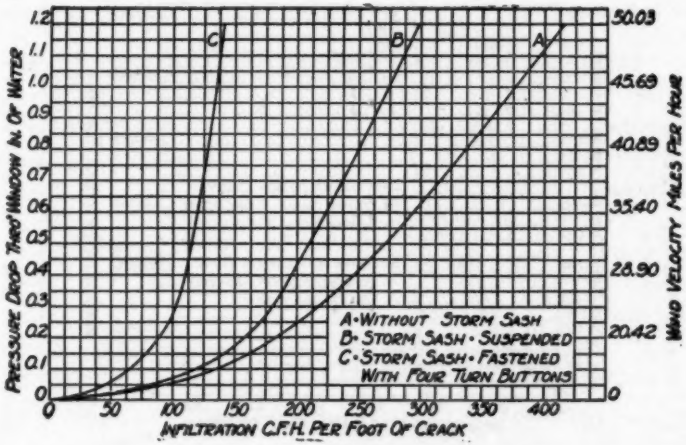

FIG. 9. INFILTRATION THROUGH SASH PERIMETER OF WINDOW WITH AND WITHOUT STORM SASH—$^{1}/_{8}$" CRACK AND $^{1}/_{8}$" CLEARANCE

constant for a given series of runs or the check runs. As stated previously the window was opened and closed several times for each test to insure an average closing. In closing the window, the only thing that was duplicated was to have the meeting rails flush. No effort was made to have the lower sash resting upon the sill of the window frame. The machine was watched and precautions were taken to see that no leaks developed in the collecting chamber. The manner in which some of the latter test data checked, previously collected data proved that no leaks had developed in the collecting chamber during the time tests were made.

Results

The pressure drop through the wall gave artificial wind velocities of desired values. The tests of windows in the Southwestern Bell Telephone Co. Bldg. at St. Louis, as reported by F. C. Houghten and M. E. O'Connell in the November, 1927, JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS,

established the fact that data collected under conditions of artificial wind pressure checked very closely with those taken under conditions of actual wind pressure. It is, therefore, reasonable to assume that the result obtained from this series of tests applies to conditions existing in actual buildings.

Table 1 gives the leakage, heat loss and square feet of radiation per foot of crack between the brick wall and the window frame. These are average values from a number of test runs.

Conclusions

The infiltration through the crack between the brick wall and window frame is a very important factor in calculating the infiltration into a room. However,

TABLE 1. INFILTRATION IN CUBIC FEET PER HOUR BETWEEN BRICK WALL AND WINDOW FRAME PER FOOT OF CRACK AND SQUARE FEET OF RADIATION NECESSARY TO HEAT SUCH LEAKAGE FROM 0 TO 70 DEG. FAHR.

	PLAIN WALL			PLASTERED WALL		
Wind Velocity Miles per Hour	Leakage Cubic Feet per Hour	Heat Loss B.t.u. per Hour	Square Feet Radiation	Leakage Cubic Feet per Hour	Heat Loss B.t.u. per Hour	Square Feet Radiation
5	20.0	25.2	0.11	4.0	5.0	0.02
10	52.0	65.5	0.27	15.0	18.9	0.08
15	89.0	112.0	0.47	28.0	35.3	0.15
20	127.5	160.5	0.67	44.0	55.4	0.23
25	170.0	214.0	0.89	58.5	73.7	0.31
30	216.0	272.0	1.13	73.0	92.0	0.38
35	258.5	325.5	1.36	86.5	109.0	0.45
40	302.0	380.5	1.59	100.0	125.9	0.52
45	344.5	434.0	1.81	114.0	143.5	0.60
50	384.0	484.0	2.02	128.0	161.3	0.67

this source of leakage can be practically eliminated by the application of some type of calking compound to the crack.

The application of storm sash does not materially decrease the infiltration of a tight fitting window, but does give a large saving if the crack and clearance of the window is large. The application of a wool strip between the frame and storm sash reduced the infiltration appreciably.

The storm sash applied by means of the four turn buttons reduced the infiltration much more than those applied by means of the hook and eye suspension arrangement.

The infiltration through the crack between the brick wall and window frame for a plastered wall is about 40 per cent of that through the same crack on a plain wall. This leakage may be as great as the leakage through the sash perimeter of the window.

Data on runs which duplicate previous tests made at the Research Laboratory check very closely with the data from that laboratory.

DISCUSSION

L. B. LENT (WRITTEN): I would like to call attention to a statement at the top of p. 551, which statement might be misleading to some not well acquainted

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with construction work. This statement is as follows: "A porous type of brick commonly known as the Chicago clay brick and ordinary lime mortar were used for the construction of this wall. These materials are used very extensively for construction purposes, and it was decided upon as one of the combinations of masonry wall to be tested."

It is hardly true that this type of construction is *used very extensively* and, therefore, does not represent anything except a very small part of the brick construction done in this country.

In the first place, Chicago brick are used almost entirely within the Chicago district. Brick produced in all other states are very largely consumed in a local market.

Lime mortar is not recommended or used where the better type of construction is required. In this case either cement mortar or cement mortar with a small part of added lime is the preferred kind. It might be well to recall that the investigation at the University of Wisconsin is not yet completed, and that the full program was intended to discover the effect of what might be called the extremes of brick quality, kind of mortar and grade of workmanship.

The test reported in the paper merely represents the poorest grade of these three factors. It should not, therefore, be taken to represent what might be called an average grade of brick masonry, although there is no such thing as an average grade. The paper might well mention these facts and further state that further investigation will, no doubt, show that with better grades of brick, mortar and workmanship the resulting infiltration might be materially reduced.

It is also a fact that in better construction, window frames are usually set in mortar all around and calked at the same time.

E. C. EVANS: I want to ask if the wall that is going to be continued in the test was built by an ordinary brick layer or whether particular attention was paid to the mortar that was placed when the wall was being built. I think this is most important. The curves show it, to compare with THE GUIDE. We find that same factor coming up. I think particular attention should be paid to that. It ought to be built at present, and then similar curves made, go through the same items of test, repeated after the wall was torn down, and another wall built by the same man, but supervised for the amount of mortar used. Definite records should be made of what the difference was, calking costs, together with cost of extra mortar, extra labor, and time, for only in that way will we get information that we can put back through the Committee of the American Institute of Architects. Let that come back for the benefit of those who have to build houses.

E. K. CAMPBELL: Continuing that same thought, I want to bring out this fact: that there is one factor that can never be determined in the laboratory; that is, shrinking of wood frames from a brick wall. In one instance in Kansas City it took half a bale of cotton to fill the crack after the building was 10 or 15 years old. The statement has been made that most buildings are having the windows calked. That is not true in the Kansas City territory.

W. C. RANDALL: I want to refer to one statement on p. 557. "It is therefore reasonable to assume that the result obtained from this series of tests applies to conditions existing in actual buildings."

There are two points involved, as I see it. First of all, as Mr. Campbell in his discussion has indicated, the authors have not taken into account the expansion and shrinkage of the wood windows in actual installation over a period of time. I think certain cracks develop in wood windows that probably are not common to a relatively new window in test conditions.

The second point that I again want to emphasize, is that they have run the pressures up to the equivalent of fifty-mile wind velocities, and the evidence which we and others have obtained would indicate that such pressures are not normally found and are probably much lower than that. A great deal more work has to be done to properly evaluate the drop in pressure to approximate actual conditions.

W. M. RICHTMANN: In reply to Mr. Evans' question on the construction of the wall, the window frame and storm sash were bought at a local lumber company, the brick from the local brick dealer, and the work was done entirely by the service department of the University of Wisconsin. This department does all the repair work around the university, and I believe is practically what you might call ordinary or common labor; the fact that the wall was to be used for testing did not change the kind of workmanship.

As time goes on we may find that leakage will develop from the shrinkage of the window frame and sash. This wall is going to be put in the storage rack and tested from time to time as the work proceeds. This is merely the result of our first year's work, and a good many things can't be brought out which may come up with the time element.

Mr. Campbell's question of shrinkage: that again is rather hard to determine in this first test, due to the fact that the window is stored in a building and is not subjected to outside weather conditions. It is a new window and consequently a certain time must elapse to give the frame and sash an opportunity to shrink.

In reply to Mr. Randall's statements we have found from the other men working on infiltration tests that we are carrying the curves into too high a range and intend in the following work to reduce our high pressures and get more data at the pressures which seem to be those under which the windows are subjected. Of course, it is rather hard, as was brought out in the previous papers, to know what a 15-mile wind velocity as recorded by the Weather Bureau is going to be in connection with the window itself; and we have merely tried to follow the practice as used in THE GUIDE and reduce our results to the same basis so they may be used in the future GUIDE Tables.

No. 818

HEATING AND VENTILATING PROBLEMS OF GAS CELL MANUFACTURE FOR AIR-SHIPS

By D. E. HUMPHREY,[1] AKRON, OHIO

MEMBER

EVERY new industry or process of manufacture brings forth new and unexpected problems, and so it was the manufacture of air-ships brought with it new and interesting problems to the heating and ventilating engineer.

There were many heating and ventilating problems in connection with air-ship manufacture, but this article is devoted to those encountered in the manufacture of the gas cells.

All lighter-than-air craft, such as the Los Angeles, are kept afloat by helium or hydrogen gas cells. Instead of having all the gas in one large cell, these mammoth ships are generally built with 16 to 20 such gas bags. The Los Angeles has 13. If one gas cell should be punctured, only a part of the buoyancy is lost, and the leaky cell may even be repaired while in flight.

The cigar-shaped hull of the rigid air-ship is not gas-tight. It contains the necessary compartments for the gas cells, runways, gasoline tanks, crew's quarters and so forth. The hull is built of rubber cloth, stretched over a duralumin structural frame. It must withstand the wind pressure, rain, ice and heat, and maintain the shape of the ship and carry the load. It is, like the casing of an automobile tire, designed for strength, wear and durability while the gas cells are like the inner tube of the automobile tire, designed to hold the gas. These gas cells are the vital part of the air-ship. They are made with great care by highly skilled workers, and of the most gas-proof substance obtainable.

Most people think of rubber or rubber-covered cloth as being gas-tight, but it is not tight enough to hold helium or hydrogen for long periods of time, without loss or dilution by osmosis. Gas cells are built of very light, high-grade, rubber-coated cotton cloth as a base, on which is applied a layer of goldbeaters' skin. This in turn is covered with a coating like varnish, for preservation and protection.

Goldbeaters' skin is the outer lining of the large intestine or caecum of an ox. This transparent, tough animal membrane is removed by the meat packers from the most suitable cattle, preserved in salt and shipped to the air-ship manufacturer. The name goldbeaters' skin was given to this membrane by the ancient gold workers

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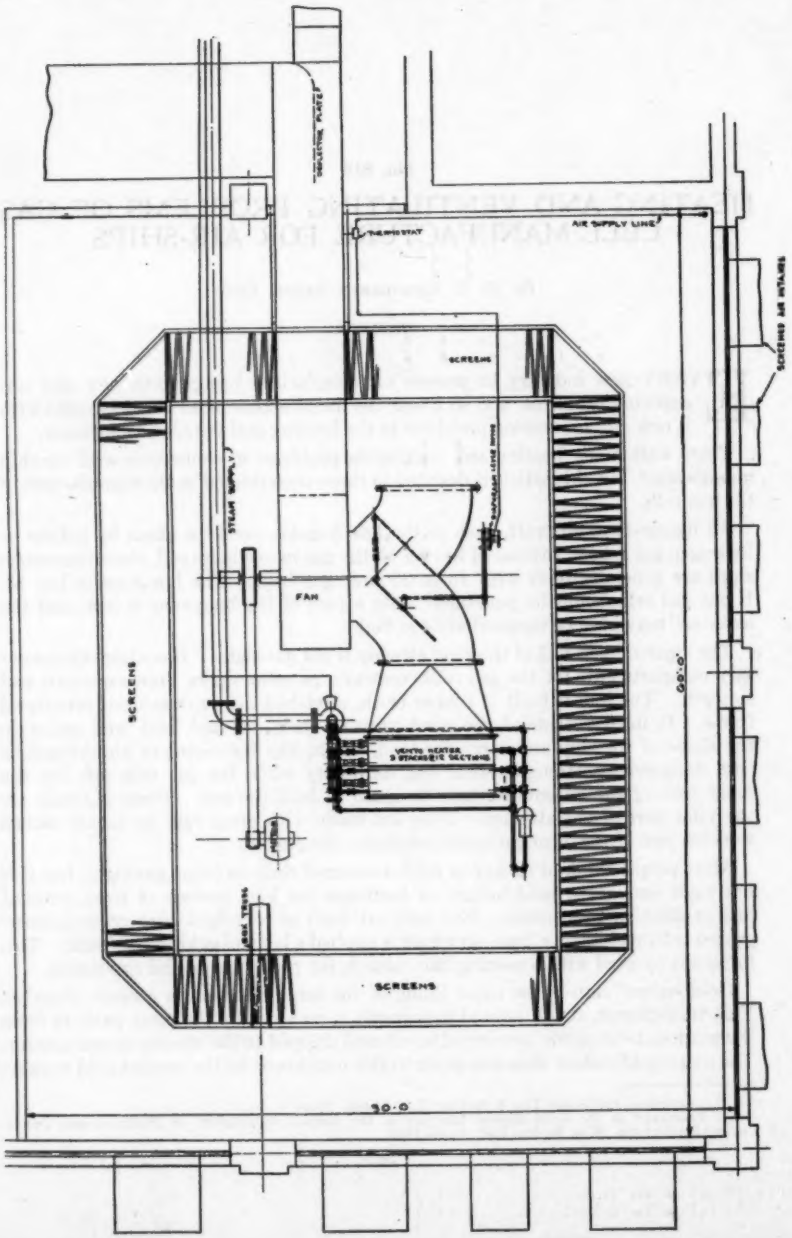
[1] Engineer, Goodyear Tire & Rubber Co., Akron, Ohio.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, West Baden, Ind., June, 1928.


DEFLECTING PLATES
THERMOSTAT
AIR SUPPLY LINE
SCREENED AIR INTAKES
SCREENS
STEAM SUPPLY
CONDENSATION RETURN
FAN
SCREENS
VENTIL HEATER
3 PITCHBEIT SECTIONS
MOTOR
SCREENS
50'-0"
50'-0"

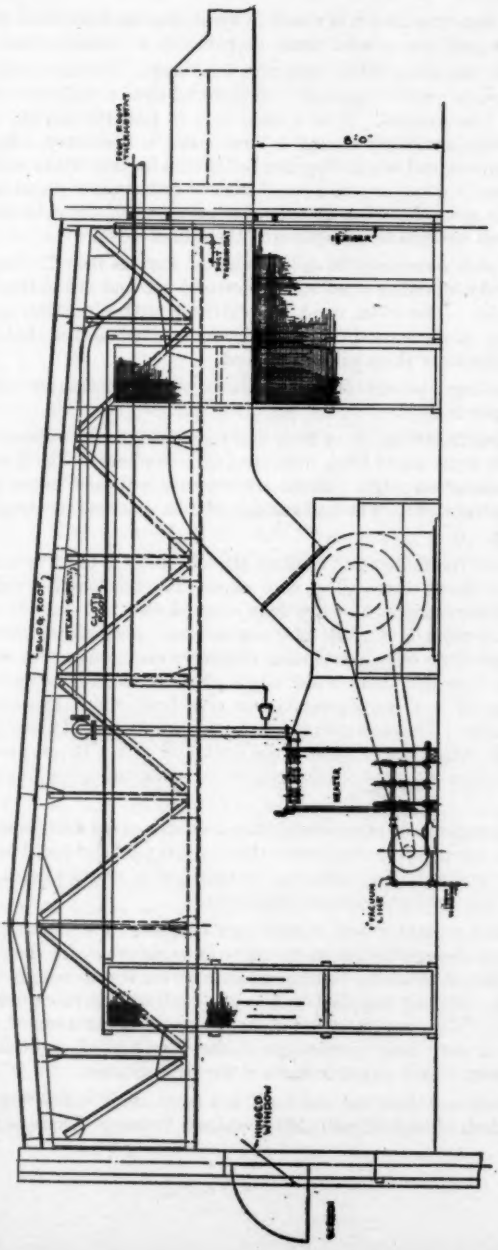


FIG. 1. LAYOUT OF THE AIR SUPPLY AND FILTERING SYSTEM DESIGNED TO PROVIDE CLEAN AIR IN ROOMS WHERE GOLDBEATERS' SKIN IS PREPARED FOR USE IN CONSTRUCTION OF GAS BAGS FOR AIR-SHIPS

of King Solomon's time, who used it as a sack in which they enclosed their gold dust, while they beat the gold into a solid mass, preparatory to making their jewelry.

Goldbeaters' skins are about 30 in. long and 8 in. wide. It takes about sixteen of them to lay a square yard of gas cell. It required over a million of them for such a ship as the Los Angeles. It is a huge task to prepare and lay all these skins. Many workers are required, and a large room is necessary, where these cells can be stretched out and where they can be inflated for inspection and testing. Scrupulous cleanliness is necessary, as a small piece of grit is apt to puncture a skin and cause a leak in a gas cell. After an extensive preparation, the skins are pieced together by hand, laid wet and dried in place on the rubber cloth.

The goldbeaters' skin room, as it is called, must be kept as near 70 deg. fahr. as possible. The relative humidity must not go above 65 per cent or the treated skins will not dry properly. The room must be ventilated with a dustless air supply in order that healthy working conditions may be maintained, and so that moisture from the drying goldbeaters' skins will be removed.

It is with the heating and ventilating problems of the goldbeaters' skin room with which this paper deals.

This room contains 28,000 sq. ft. of floor and roof area and its volume is about 450,000 cu. ft. The walls are of brick with steel sash windows. The floor is built of two by fours packed on edge. These are covered with tar paper and then surfaced with matched maple. The roof consists of 2-in. matched sheeting, covered with asphalt roofing.

In order to prevent the infiltration of dirty air, all cracks in the windows, walls, roof and around the floors were calked with okum and then puttied tight. The walls and ceilings were painted, and the floor covered with canvas. It might be thought that such a room is *air-tight* but a great deal more air passes through such floors and walls than even ventilating engineers are accustomed to believe. It was desirable to have this room under slight pressure, in order to prevent the infiltration of dusty air. A ventilating system was built which supplied 30,000 cu. ft. of air per minute. The air was drawn in from the outside and filtered through a specially designed cloth filter to remove the dust and dirt. It was then heated by steam coils at the fan intake and delivered to the room through a long overhead distributing duct.

It is difficult to imagine any commercial dust collector or air filter which cleans the air which passes through it so completely that no dust particles could be detected in it. Clean air as applied to dust collection is therefore a relative term which is used to represent a satisfactory degree of cleanliness.

For instance, a dust separator such as used on the exhaust of a foundry tumbling barrel might separate enough dust from the air to be satisfactory for the conditions around a foundry, but it would be entirely inadequate for the air supply to a goldbeaters' skin room. The air supplied to the goldbeaters' skin room has been described as dustless. This was interpreted to mean the separation of all gritty dust particles and a very large percentage of the very fine black or lint which causes discoloration on a light object in front of the air discharge.

The air filter which was designed and built is a large affair, consisting of about 17,000 sq. ft. of cloth stretched over 160 V-shaped frames. These screens are

erected in an upright position, forming a rectangular filter enclosing the fan, heater and mixing dampers. This filter in turn is enclosed within a plenum chamber, to which air is admitted from the outside. At weekly intervals the fan is shut down and the screens cleaned with a special vacuum cleaner tool. The results from the filter are quite satisfactory.

The heat losses of the room are taken care of by direct radiation and the temperature of the air supplied by the ventilating system is regulated in order to warm the air in cold weather and to control the humidity in the room. This is accomplished by a duct thermostat, which controlled a set of mixing dampers, also a room thermostat, which controls the steam supplied to the heating coils.

Arrangements are made to cut in or out either one of these temperature controlling systems so that the one best suited to meet the conditions wanted could be used.

As no provisions were made to remove the air from the room, and as this room was made as tight as possible, there was a question as to whether 30,000 cu. ft. of air per minute would find its way out through the painted brick walls, asphalt papered floor and roof, without building up an internal pressure. Preparations were made to install ventilators on the roof, in order to relieve the pressure, if necessary.

When the fan was started, a hole was bored through the window sash and the pressure between the inside and outside of the room was taken on a water gage, which read to the hundredth of an inch. This gage showed an internal pressure of not to exceed two one-hundredths of an inch. This of course was so small that no roof ventilators were necessary.

The 30,000 cu. ft. of air per minute gives an air change in the room once every 15 min. which is sufficient to remove the moisture from the drying goldbeaters' skins, to keep the air pure and also to keep the relative humidity below 65 per cent during the cooler weather.

When the room was designed, dehumidification by refrigeration was considered. It was found that an air conditioning system for a room of this size and character would be very expensive. An estimate of the contemplated work of building gas cells showed that it would be completed before the hot, humid days of summer arrived. It was therefore decided to rely on temperature control and air change to maintain a humidity of less than 65 per cent, and the air conditioning plant was not installed.

As it happened, the work extended beyond the estimated time, and warm weather came before the job of laying goldbeaters' skins was completed. The temperatures of the air at Akron, O., are seldom too high for the work, but when the summer sun shown on the roof, the heat transmitted through the asphalt roof was estimated to be between 600,000 and 700,000 B.t.u. The 15-min. air change was not enough to remove this heat, and the room became too warm and the humidity went above the point where goldbeaters' skins would dry properly. It was then necessary to devise some means of disposing of the heat transmitted through the roof after it had entered the room, or some way of eliminating it, or preventing it from entering the room.

A thermometer inserted in the hot asphalt of the roof read 140 deg. fahr., but

when a piece of wet cotton was placed over the bulb of this thermometer, it dropped to a point not much above the wet-bulb temperature. This experiment showed the possibility of reducing the solar heat transmitted through the roof by wetting the roof. It was decided to install a system of water sprays on the roof in order to cool it when the sun shone.

Spray nozzles similar to those used in the air washer, but of a larger size were spaced so they would wet the entire roof over the goldbeaters' skin room. The excess water from these nozzles ran down the eavespouts. Of course the drop in temperature which was secured by wetting the roof would depend on the relative humidity of the air, the wind and certain other conditions which effect evaporation. The reduction in roof temperature was sufficient. The heat transmission through the roof was cut down so that the work of building gas cells could be completed. One spray nozzle wet about 500 sq. ft. of roof satisfactorily, and the expense of installing them was small compared to roof insulation or additional equipment for removing the heat after it had once entered the room.

The experience with the manufacture of gas cells for air-ships has demonstrated in a practical way three things which are of interest to the heating and ventilating engineer, namely:

1. The efficiency of a properly designed cloth filter for separating the dust from the air of a ventilating system.
2. The passage of air through floors, walls and roof of a building which was supposed to be air-tight.
3. And the use of water sprays to wet the roof of a building to reduce the heat transmitted through the roof.

DISCUSSION

J. M. ROBB (WRITTEN): Mr. Humphrey is to be complimented for the straight line thinking that caused him to solve his problem as he describes.

In the matter of filters, however, if he had investigated those of the rotary type, I think that he would have found a solution that would require less housing, and less labor cost, to maintain. Probably, also, the initial cost would be less.

His use of a vacuum cleaner to clean his filter screens is particularly admirable.

A better appreciation of the value of proper vacuum cleaner equipment in ventilation work would greatly benefit the entire industry. At present, the general notion of the value of an adequate vacuum cleaner application, in ventilation results, has received too little attention.

If the use of water to flood the roof, in order to reduce summer temperatures, were measured, the publication of the quantity required, for a given cooling effect, might encourage a wider use of such applications.

The report of the amount of air leaking through building construction, after unusual effort had been made to stop leakage, is especially interesting.

In checking ventilation applications in well-constructed school buildings, I have found that the leakage approximated as high as nine air changes of contents per hour, under about the same pressures.

Mr. Humphrey's study, as to air leakage, emphasizes the importance of the recommendation that J. A. Donnelly has been making, for many years, that each building that is heated be calibrated for its leakage and other heat losses. More studies of this nature would materially increase our knowledge of the true relation between cause and effect in many of the things that occur in heating and ventilating practice.

Until a definite answer can be given to the question "How much air does the building leak?" all of our assumptions as to a given heating and ventilating result are mere assumptions. This alone will account for much of the differences of opinion as to various methods to produce a given effect.

Control of air pressures within a structure is essential to the maintenance of uniform temperatures. Leakage studies, such as Mr. Humphrey's, are of greater importance and value than such studies as are now being made of the leakage with various types of windows. In this assertion, there is no lack of appreciation of the value of the work that has been done, of this nature, or of the work that is now going on. All this work is of great value. But there are many other items that affect air leakage in buildings. And such studies as Mr. Humphrey's reports are necessary to discover these items.

When such studies are made, and their results are more generally understood, consulting engineers will form new conceptions of the value of unit ventilators, and of corridor venting, which is successful only with unit ventilation.

L. L. LEWIS: I would like to have the privilege of congratulating Mr. Humphrey on discovering a most ingenious way of getting out of a difficulty, and a most interesting description of it. It seems it is the solution of these little problems that form the other part of our compensation for our work and make it a real pleasure.

I find in reading the paper, however, the impression may be gained that the results obtained with this system were comparable with those which might have been obtained with the more expensive system of dehumidification with refrigeration.

There are two general methods by which temperatures and humidities may be maintained: *First*, is with a humidifying system in which certain cooling is obtained with evaporation. Summer temperatures are limited to those which can be obtained with evaporative cooling. Such a system would in this plant have maintained something like a maximum temperature of ninety degrees with a relative humidity of 65 per cent. This maximum temperature would be reached only during the real hot days during the summer. As the weather moderated lower temperatures would be maintained until finally seventy degrees would be reached. With the other system, refrigeration and dehumidification, a constant temperature of 70 deg. fahr. could be maintained throughout the entire summer.

Naturally with the inside at 70 deg. fahr., and the outside considerably higher, an inward radiation would take place, and, therefore, the air conditioning equipment, the fan and the duct system, would have to be somewhat larger than the evaporative cooling system, and naturally the addition of refrigeration to such a system would make it considerably more expensive.

I do not believe that such a system would have been warranted in this case be-

cause there are not many products, not many processes for which an absolutely uniform temperature is demanded.

The filter, which I think I know, is a very difficult one to handle. The cloth can be made to do better cleaning than any other device that we know. A good felted cloth is the only thing that I know of with which smoke can be removed. But it is an extremely awkward thing to handle, and I can well imagine that the space limitations of this particular installation had no little to do with the design that was finally decided upon.

However, where an extreme degree of cleanliness is demanded, I believe that it has been found that the place for the filter is on the discharge side of the fan. In that case air leakage would be outward instead of inward as with the apparatus used. There are necessarily cracks in this filter chamber just as there were in the room so that there would be an infiltration of uncleaned air due to the suction of the fan.

To put such a filter on the discharge side of the fan requires a large space. Some air is lost, but it is lost in the proper direction.

I would like again to say to Mr. Humphrey that I enjoyed his paper very much indeed.

D. E. HUMPHREY: This design of filter or the method by which we kept our humidities and temperatures down is not offered as a substitute for air conditioning. For this particular job the methods described gave satisfactory results. I do not agree with Mr. Lewis that the discharge side of the fan is always the best location for a cloth filter. Better distribution of the air over the cloth is generally secured when the filter is on the suction side.

I have in mind a lamp-black filter installation where leaks in a pressure filter would be objectional, while if the filter was under suction, no objectionable black would escape. In sand-blast dust filters, as well as in case of the goldbeaters' skin room filter, which I have just described, it would seem to me preferable to have the filter under suction.

IN MEMORIAM

Names	Joined the Society	Died
Thomas Barwick	Charter Member	Feb. 1928
Henry J. Burt	May 1926	July 1928
James Doherty	Nov. 1917	Jan. 1928
George A. Eagan	June 1917	Feb. 1928
Edward H. Giles	June 1919	Apr. 1928
John H. Kinealy*	Charter Member	May 1928
James W. Kingsbury	May 1924	Jan. 1928
Walter J. Kline	June 1912	Nov. 1928
Byron E. La Follette	Nov. 1916	Nov. 1928
Alfred S. Mappett	Charter Member	Apr. 1928
Thomas G. Mouat	Oct. 1914	June 1928
Robert M. Peterman	Aug. 1917	May 1928
Walter S. Timmis*	Dec. 1911	Apr. 1928

* Past President.

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